NIST Overview
MEMS and Nanotechnology

Michael Gaitan
MEMS Project Leader

National Institute of Standards and Technology
Semiconductor Electronics Division
Department of Commerce

Department of Commerce

Donald Evans
Secretary

Secretary
Deputy Secretary

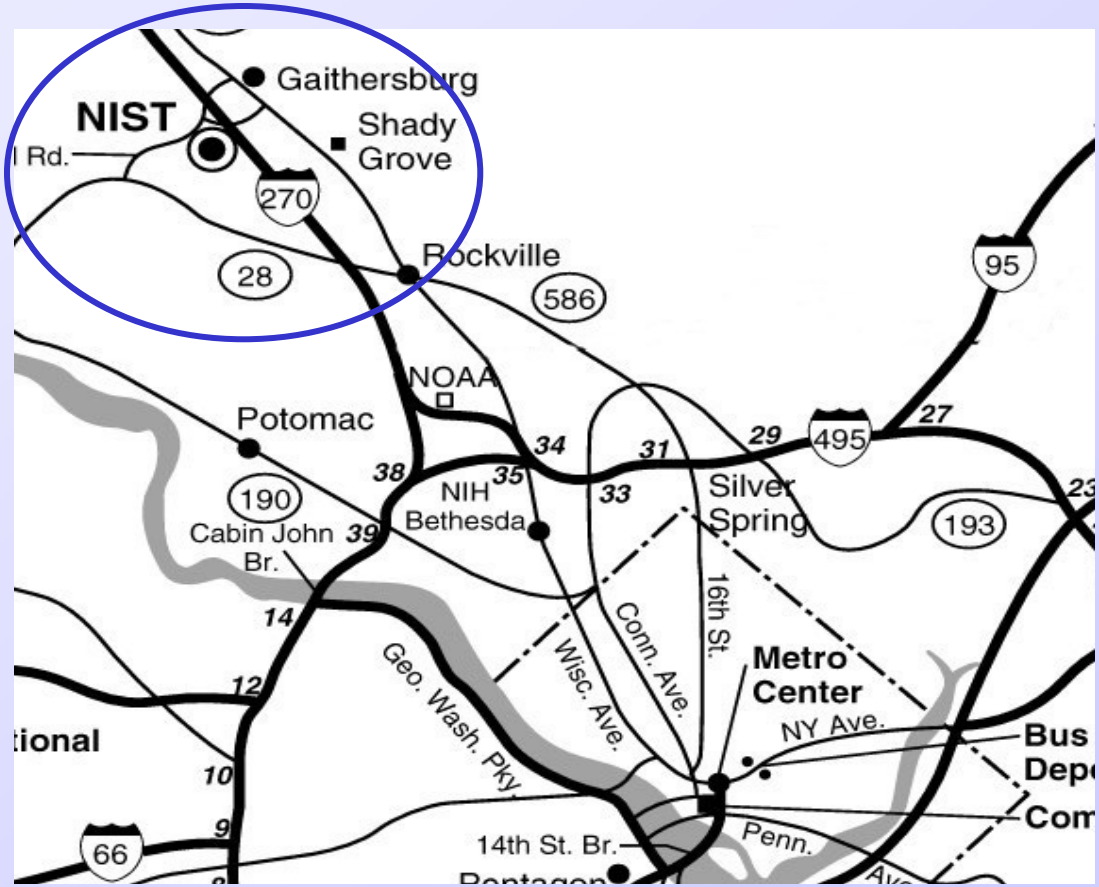
- National Oceanic and Atmospheric Administration
- Patent and Trademark Office
- National Telecomm. & Info. Administration
- (Other bureaus)
- Technology Administration
  - National Technical Information Service
  - Office of Technology Policy
  - National Institute of Standards and Technology

Dr. Samuel Bodman
Deputy Secretary

Phillip Bond
Under Secretary

Dr. Arden Bement
Director

Dr. Hratch Semerjian
Deputy Director (Acting)



Washington DC

NIST Has Two Campuses…

Gaithersburg, MD

Boulder, CO

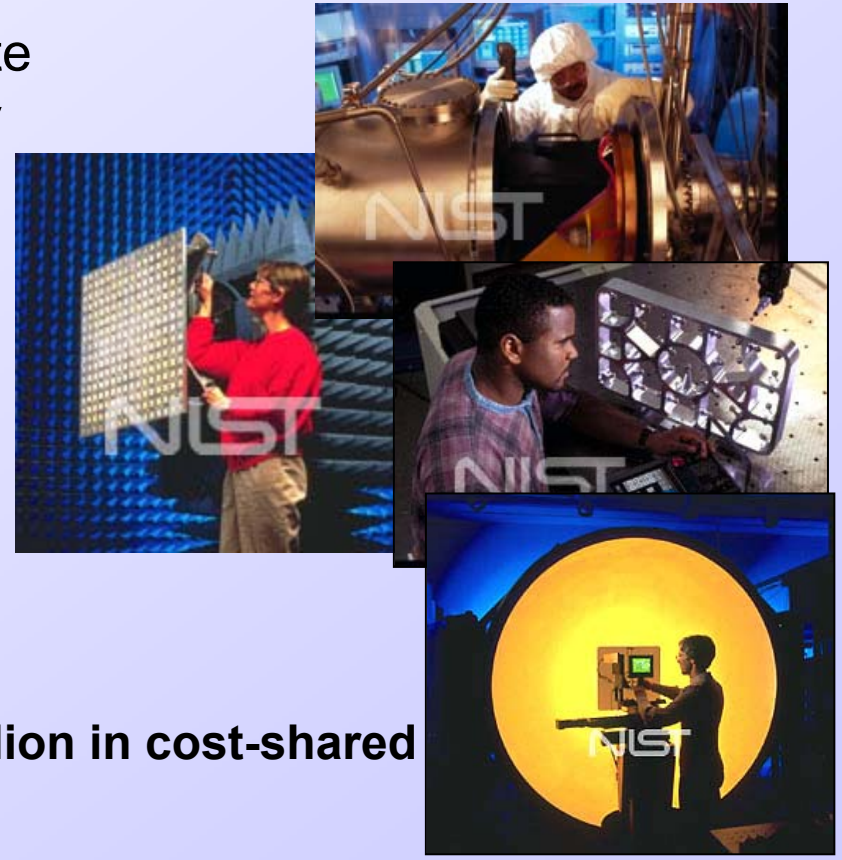
..and two joint Institutes

CARB
University of Maryland

JILA
University of Colorado

NIST: A Unique Mission and Assets

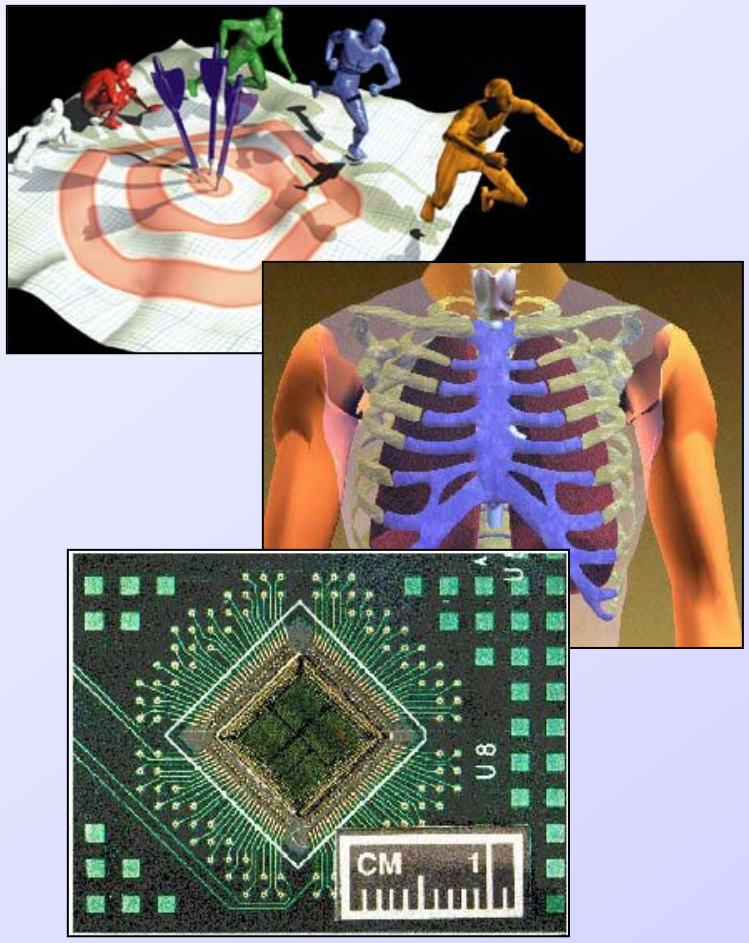
NIST's mission is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life.



NIST Assets Include:

- **3,000 employees**
- **1,600 associates**
- **$825 million FY 2003 operating budget**
- **Advanced Technology Program -- $4 billion in cost-shared partnerships with industry since 1990**
- **Manufacturing Extension Partnership -- 400 centers nationwide to help small manufacturers**
- **Baldrige National Quality Award**
- **NIST Laboratories -- National measurement standards**

NIST Advanced Technology Program



- **Co-funding of private sector R&D to accelerate the development of high-risk, broadly enabling technologies.**
- **Auto Body Consortium - improved fitting of parts to save money for manufacturers and consumers**
- **Tissue Engineering - new materials to repair damaged ligaments and tendons: several billion dollar impact**
- **“DNA Chips” - new technology for cheap, rapid genetic analysis**

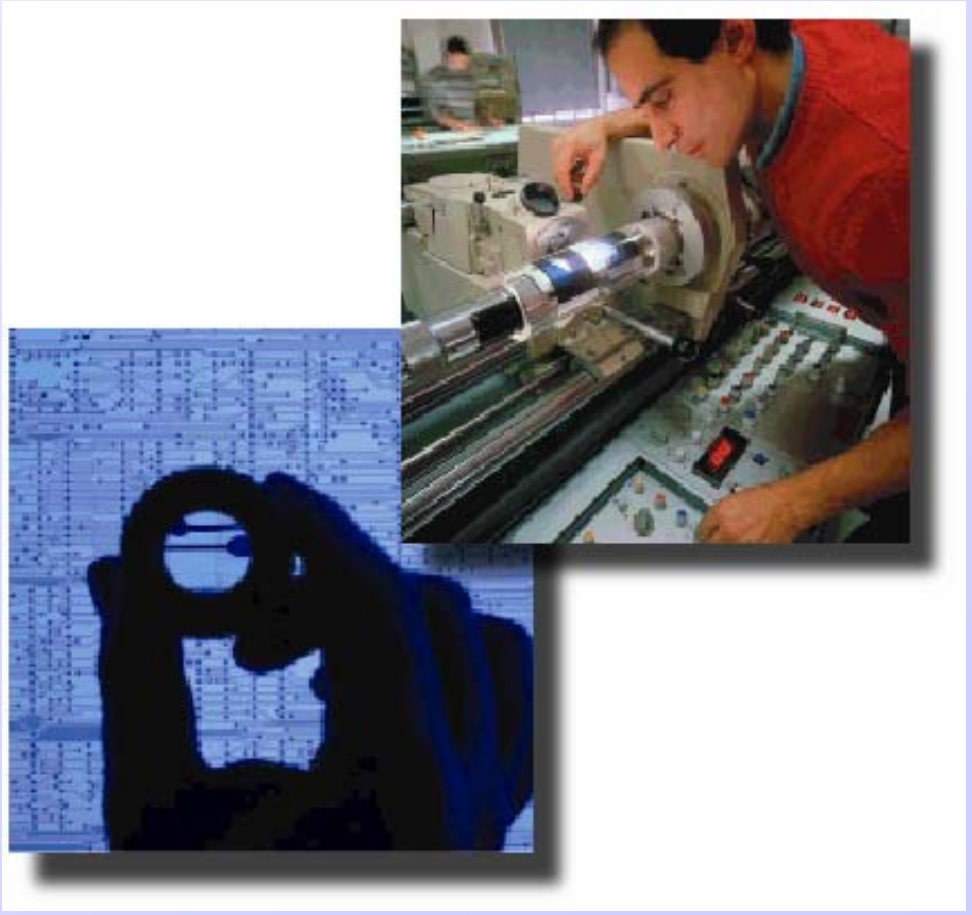
www.atp.nist.gov

Manufacturing Extension Partnership

- **Nationwide network providing hands-on help to smaller manufacturers to become globally competitive**

- **Business assistance**
  - **Quality management**
  - **Human resource development**
  - **Financial planning**
  - **Other services**

- **Technical assistance**
  - **E-commerce**
  - **Process improvement**
  - **Plant layout**
  - **Product development**
  - **Energy audits**
  - **Other services**



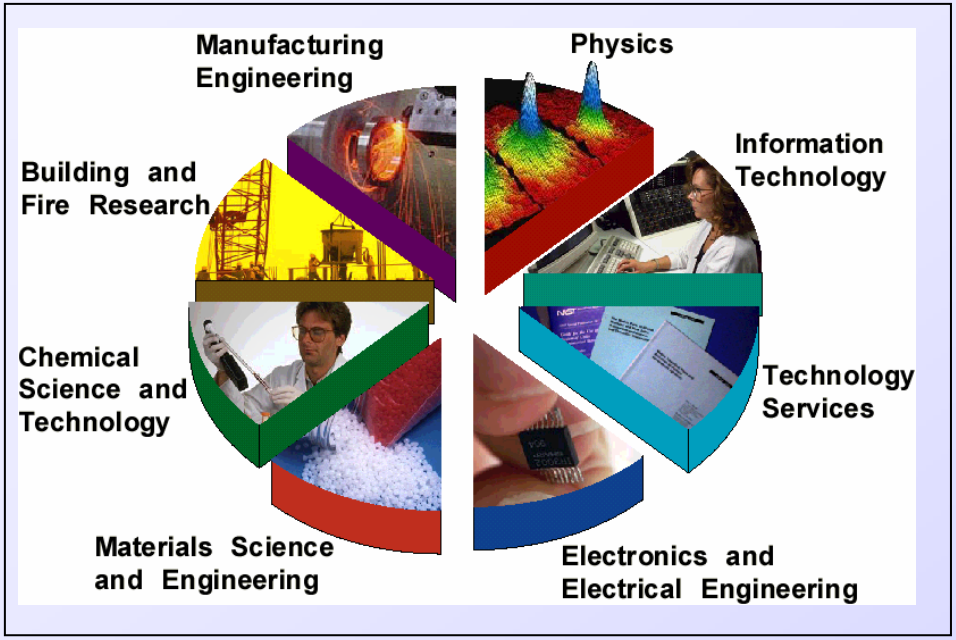
www.mep.nist.gov

Baldrige National Quality Program

- Premier U.S. award for performance excellence and quality achievement.
- Awards in Manufacturing, Service, Small Business, Education, Health Care.
- More than 2 million copies of Criteria for Performance Excellence distributed (not including downloads from Web).

www.baldrige.nist.gov

NIST Laboratories and Technical Staff



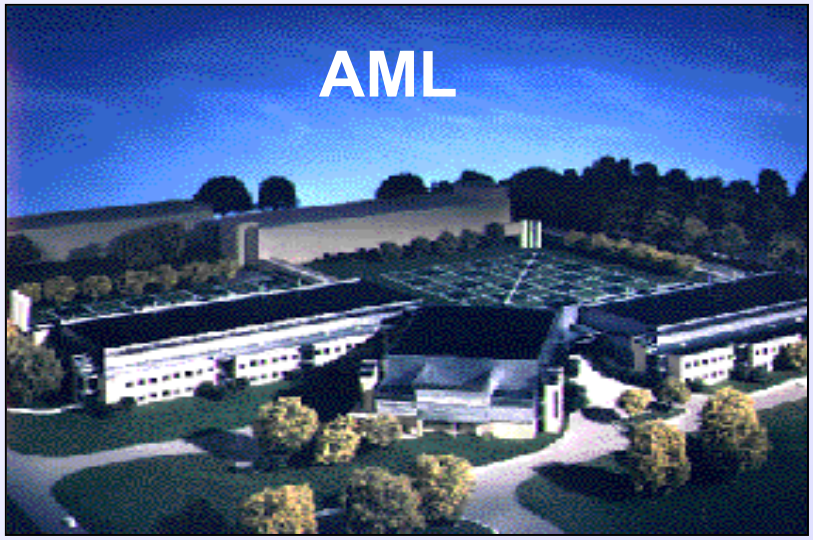
Multidisciplinary expertise to develop measurements and standards to enable:

- ❑ Science
- ❑ Technology innovation
- ❑ Trade
- ❑ Public benefit

NIST plans and works in close collaboration with customers:

- ❑ Industry
- ❑ Other agencies
- ❑ State and local governments
- ❑ Measurement laboratories
- ❑ Standards development organizations

Unique Measurement and Research Facilities



Advanced Measurement Laboratory :

- Unparalleled environmental control
- Nanofabrication Facility
- Completion targeted for 2004

Advanced Chemical Sciences Laboratory

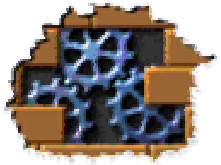
- Critical capabilities in nanobiotechnology and analytical chemistry

NIST Center for Neutron Research

- Most versatile neutron facility in the US with over 1750 users annually

http://www.memsalliance.org

MEMS Alliance



An alliance of companies, universities, and government laboratories in the Washington DC metropolitan area. Our mission is to create a group that networks expertise, capabilities, and research to facilitate the development of new applications and commercialization of miniaturization technologies.

www.memsalliance.org

Maryland
Washington DC
Virginia

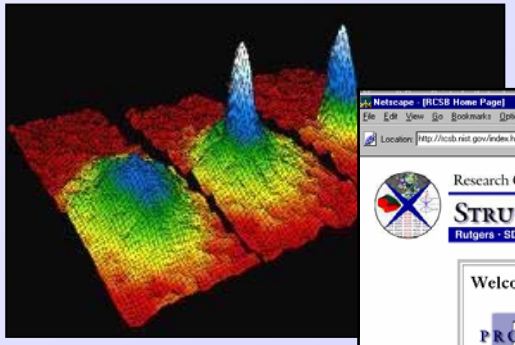
MEMS
Microfluidics
BioChips
Microfabrication
Microsystems
Cell Phone on a Chip

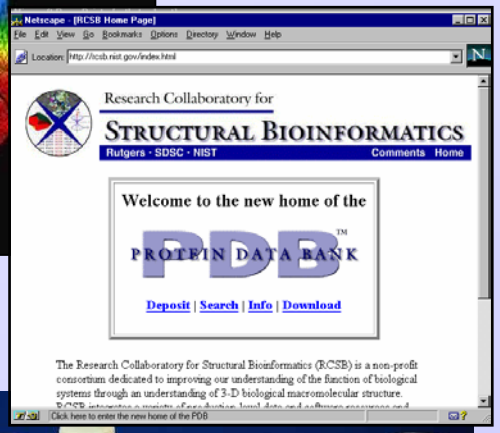
An Allicance Of:
Companies
Universities
Government Laboratories

MANA – Mid-Atlantic Nanotechnology Alliance

NIST Products and Services

- **Measurement Research**
  2,200 publications/year
- **Standard Reference Data**
  90 types available
  5,500 units sold/ year
- **Standard Reference Materials**
  1,300 products available
  31,000 units sold/year
- **Calibrations and Tests**
  3,000 items calibrated/year
- **Laboratory Accreditation**
  819 accreditations
- **Standards Committees**
  440 NIST staff, 970 committees





Strategic Focus Areas

NIST 2010

- ❑ Health Care
- ❑ Nanotechnology
- ❑ Homeland Security
- ❑ Information / Knowledge Management

MEMS and Nanotechnology
Overview

- Standardization
  - Measurement Methods
  - *e*-Standards
  - Manufacturing

- Devices for improved measurements
  - NanoBioTechnology
    - Single molecule measurements

Standardization Groups

Task Group Descends On Micro-Technology

An ASTM task group is working with tiny mechanical parts smaller than the width of a human hair. Work on microelectromechanical systems (MEMS) standardization is under way in Task Group E08.05.03 on Structural Films and Electronic Materials, under Subcommittee E08.05 on Cyclic Deformation and Fatigue Crack Formation, in Committee E-8 on Fatigue and Fracture. Scientists experienced in fatigue and fracture and/or creep-process are sought for development of MEMS test methods.

In these tiny systems, barely visible gears, hinges, motors, and other mechanical components are manipulated by micro-tweezers and probes, and viewed with scanning electron microscopes. "Imagine everything in day-to-day life being miniaturized: gears, wheels, motors, turbine engines, everything. My whole fatigue testing machine fits on a silicon chip a few hundred microns square," said Task Group Chairman Chris Muhlstein, a materials scientist in the Materials Science and Engineering Department, University of California, Berkeley.

MEMS are made from combinations of metals, ceramics, and polymers. "The little nozzles on your ink-jet cartridge are probably one of the

(CONTINUED ON NEXT PAGE)

COURTESY OF SANDIA NATIONAL LABORATORIES

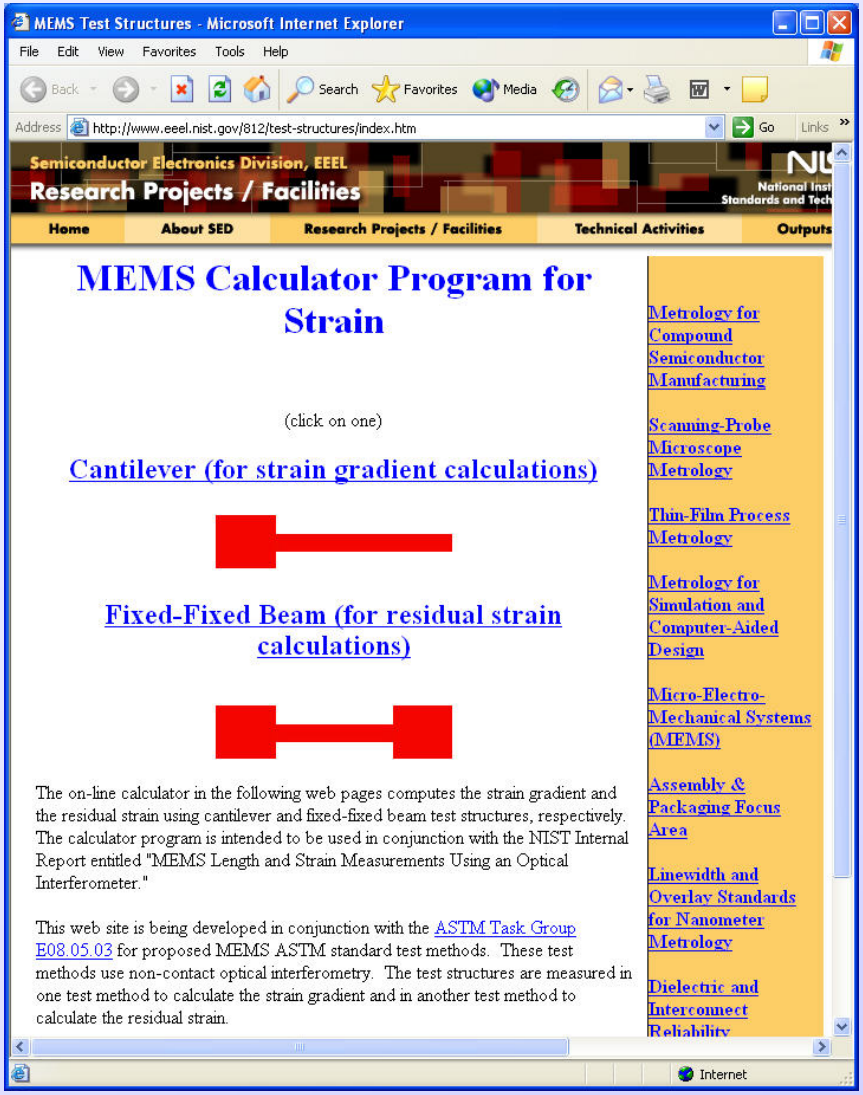
Smaller than the width of a human hair, microscopic gears of this type are used in polysilicon microengine transmissions, an important application for new ASTM standards.

- ASTM
  - Task Group E08.05.03
  - Est. 1998
  - Measurement Methods - Residual Stress, Elastic Modulus
- Micromachine Standardization Forum
  - Japan's MMC
  - Est. 2000
  - Terminology
- SEMI
  - IMSG - International MEMS Standardization Working Group
  - Est. 2003
  - Manufacturing

Dimensional Measurements of MEMS Test Structures

- NIST Report on measurement of length and strain measurements.
- 3 ASTM Test methods for dimensional and strain measurement are completed.
- A round robin experiment to determine precision and bias is in progress.

e-Standards

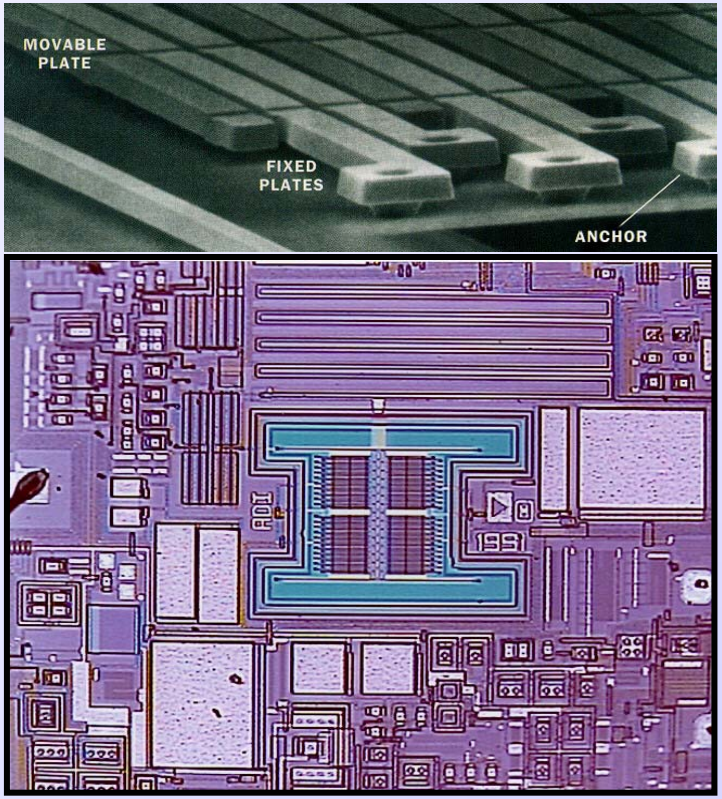


On-line hyperlink documents that:

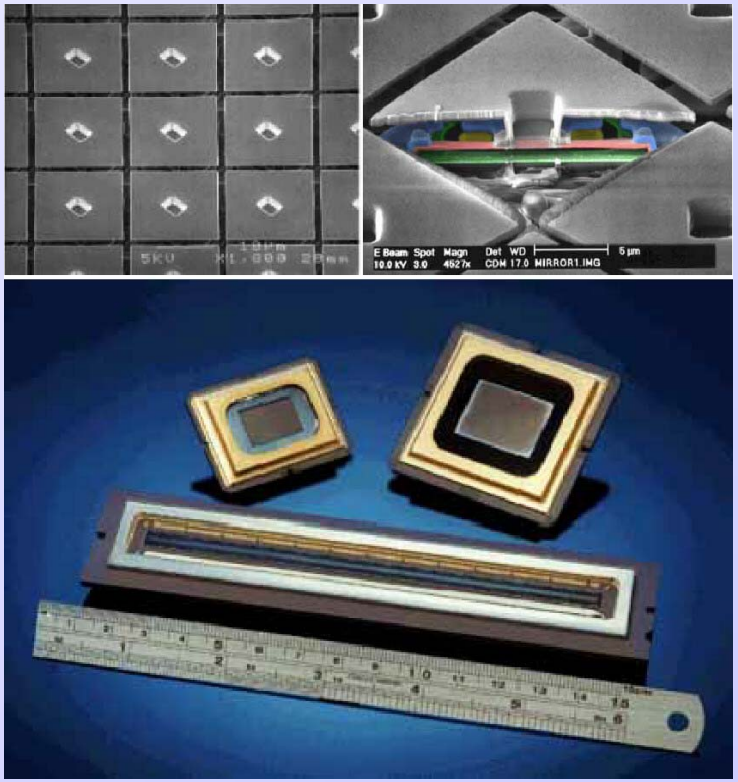
- Provide a guide through the measurement procedure.
- Currently: cantilevers and buckled beams.
- Will provide links for explanations to questions the user might have.
- Will include other information such as web links to other standards, references, and people to contact.

Systems

Commercial Examples

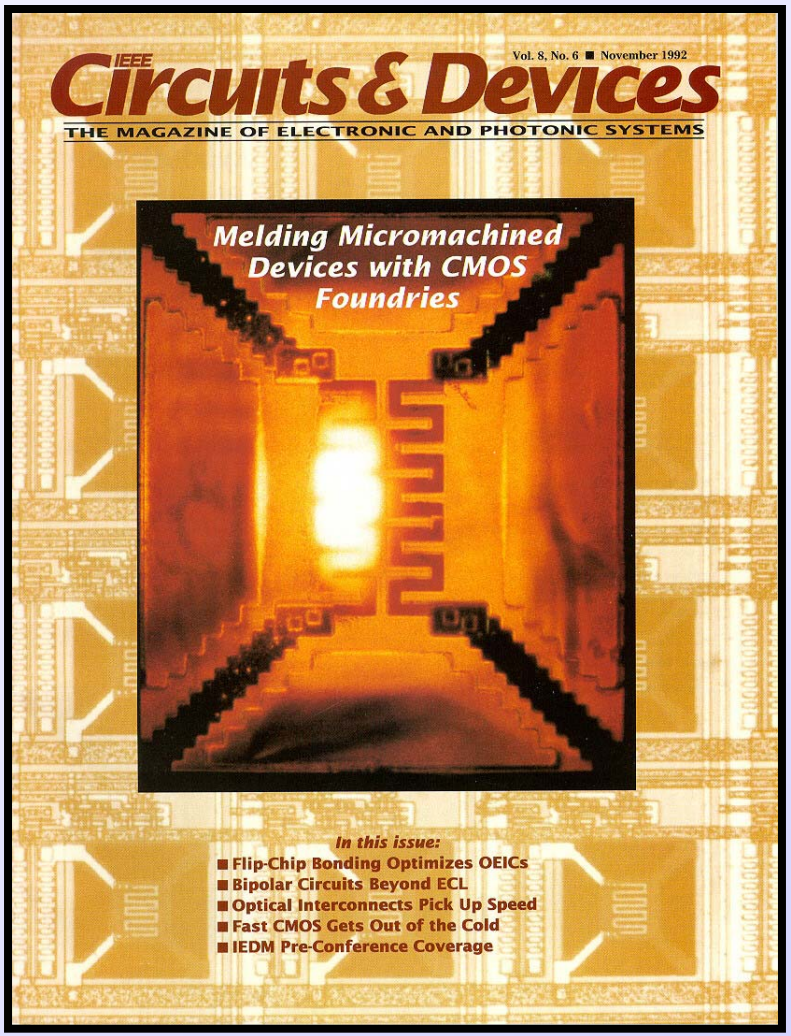


Analog Devices
Accelerometer



Texas Instruments
Deformable Mirror Display

Manufacturing



CMOS-Integrated Circuit-Foundry MEMS – *cif*-MEMS

Circuits and Devices: "Melding Micromachined Devices with CMOS Foundries," November 1992

http://www.mosis.org/Products/mems.html

cif-MEMS

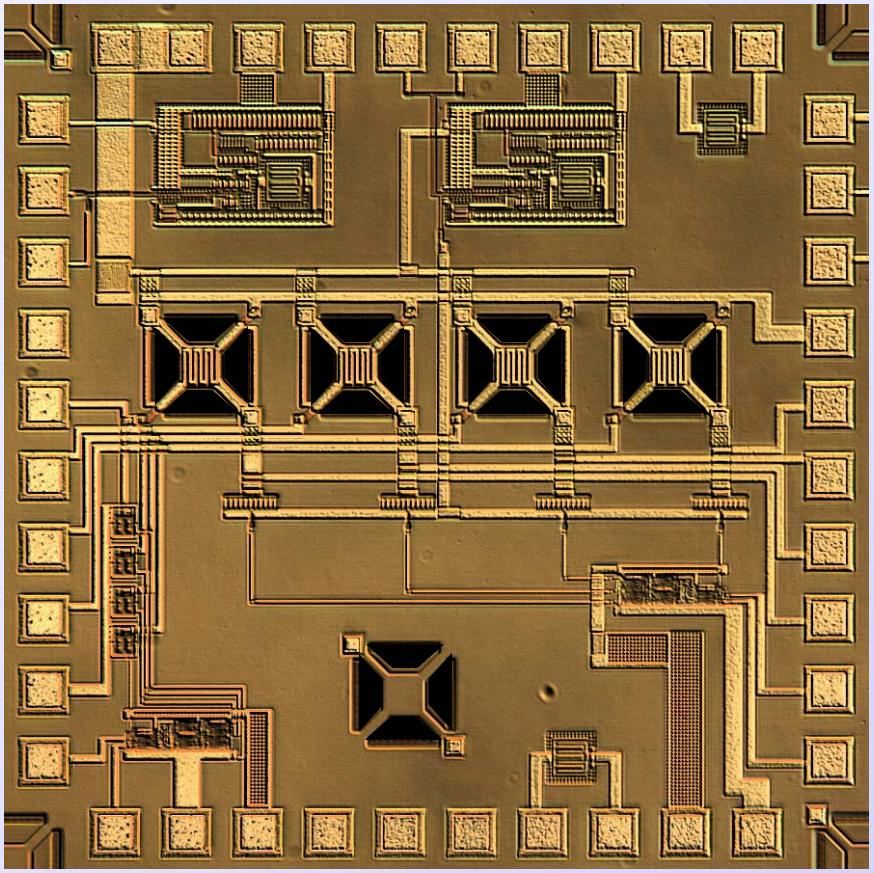
- Devices
  - Thermal-Based Elements

    Thermal Displays, Microhotplate Gas Sensors, Convective Accelerometers, Flow Sensors, Vacuum Sensors, Microchemical Reactors
  - Microwave Elements

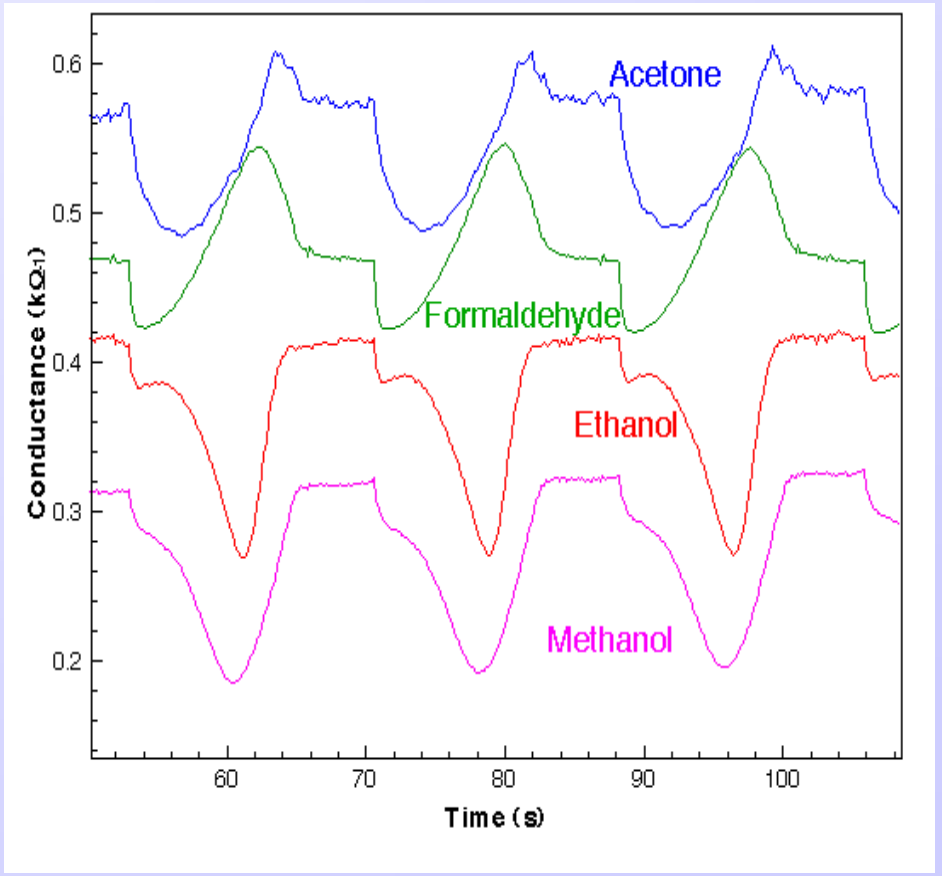
    Spiral Inductors, Coplanar Transmission Lines, Antennas, Resonant Filters, Power Sensors
  - Electromechanical Elements

    Resonators, Accelerometers, Micro mirrors

Microhotplate Gas Sensors

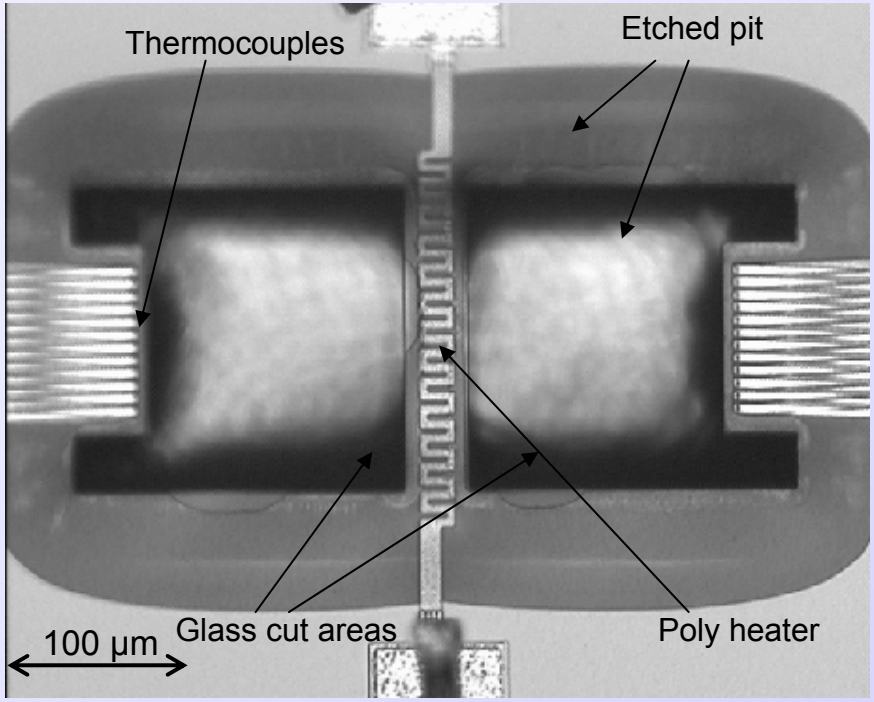


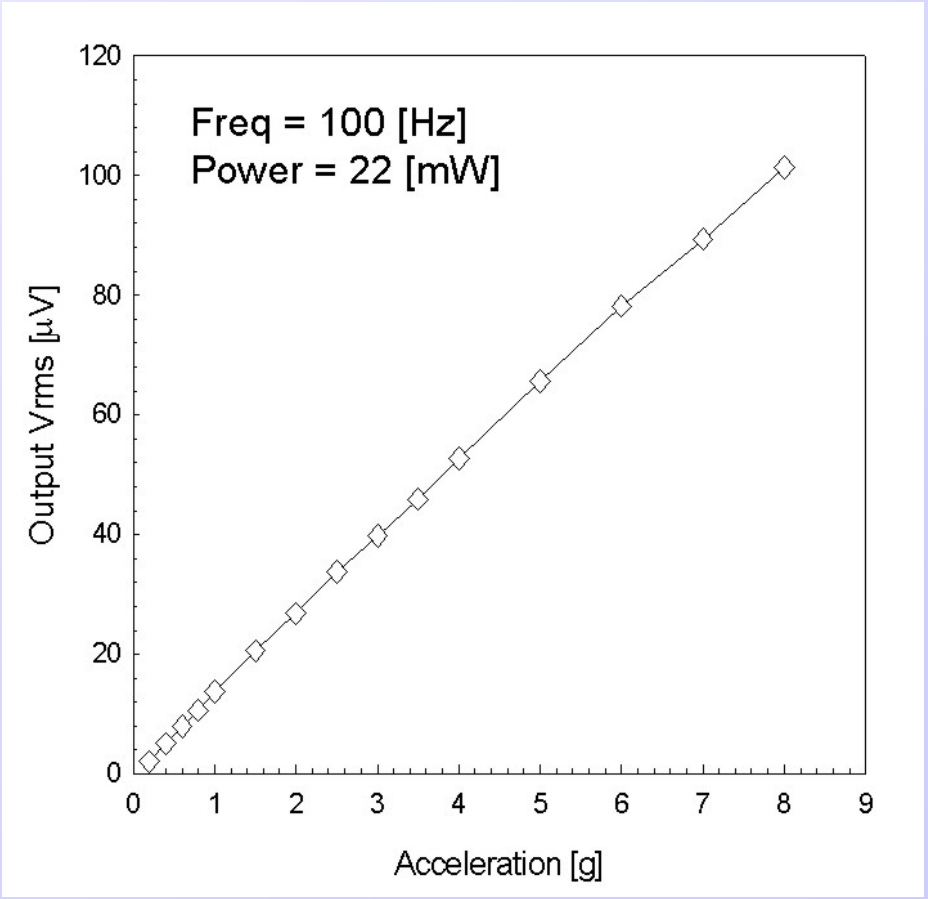
Semiconductor Electronics Division EEEL

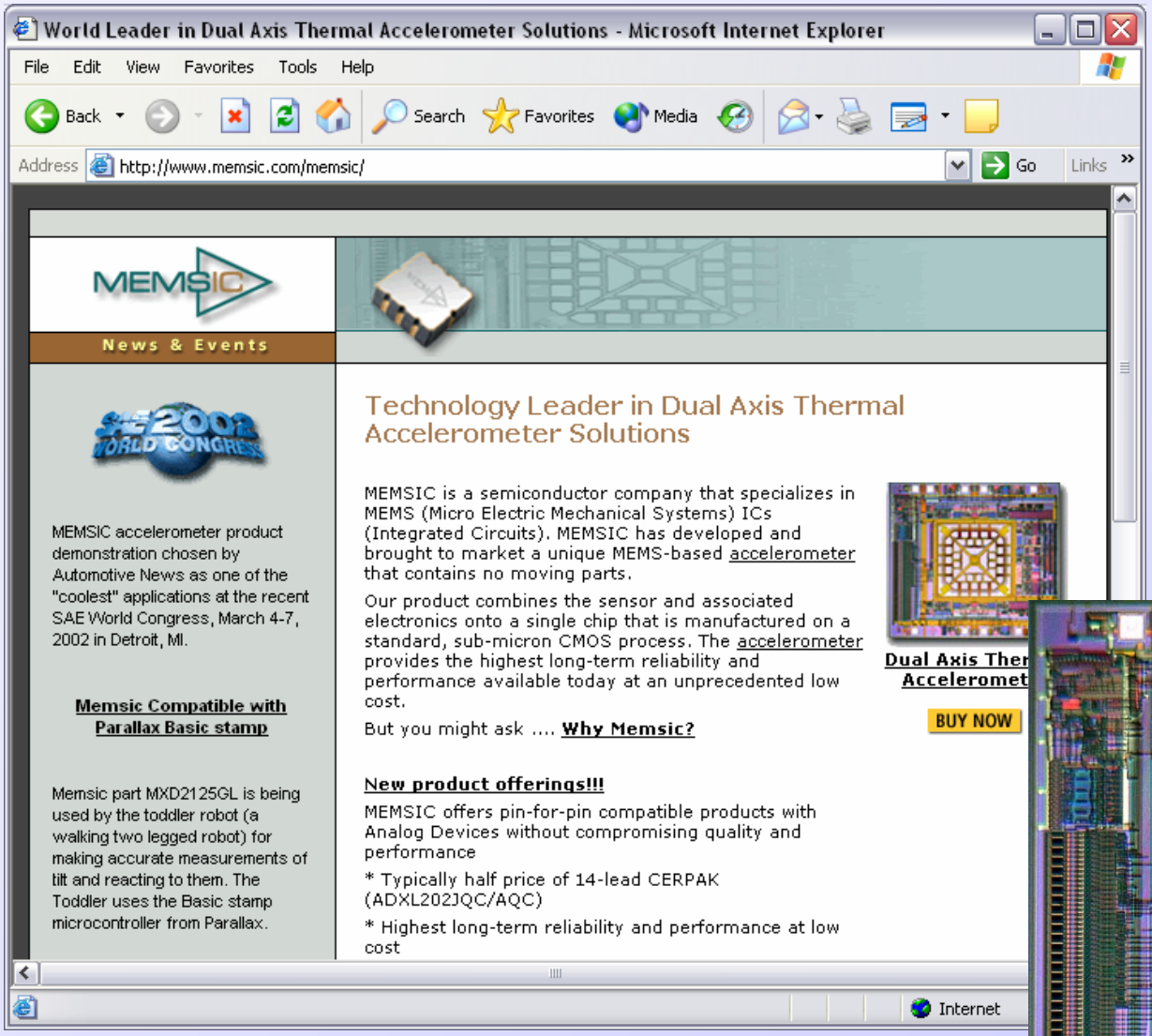


Process Measurements Division CSTL

Convective Accelerometer

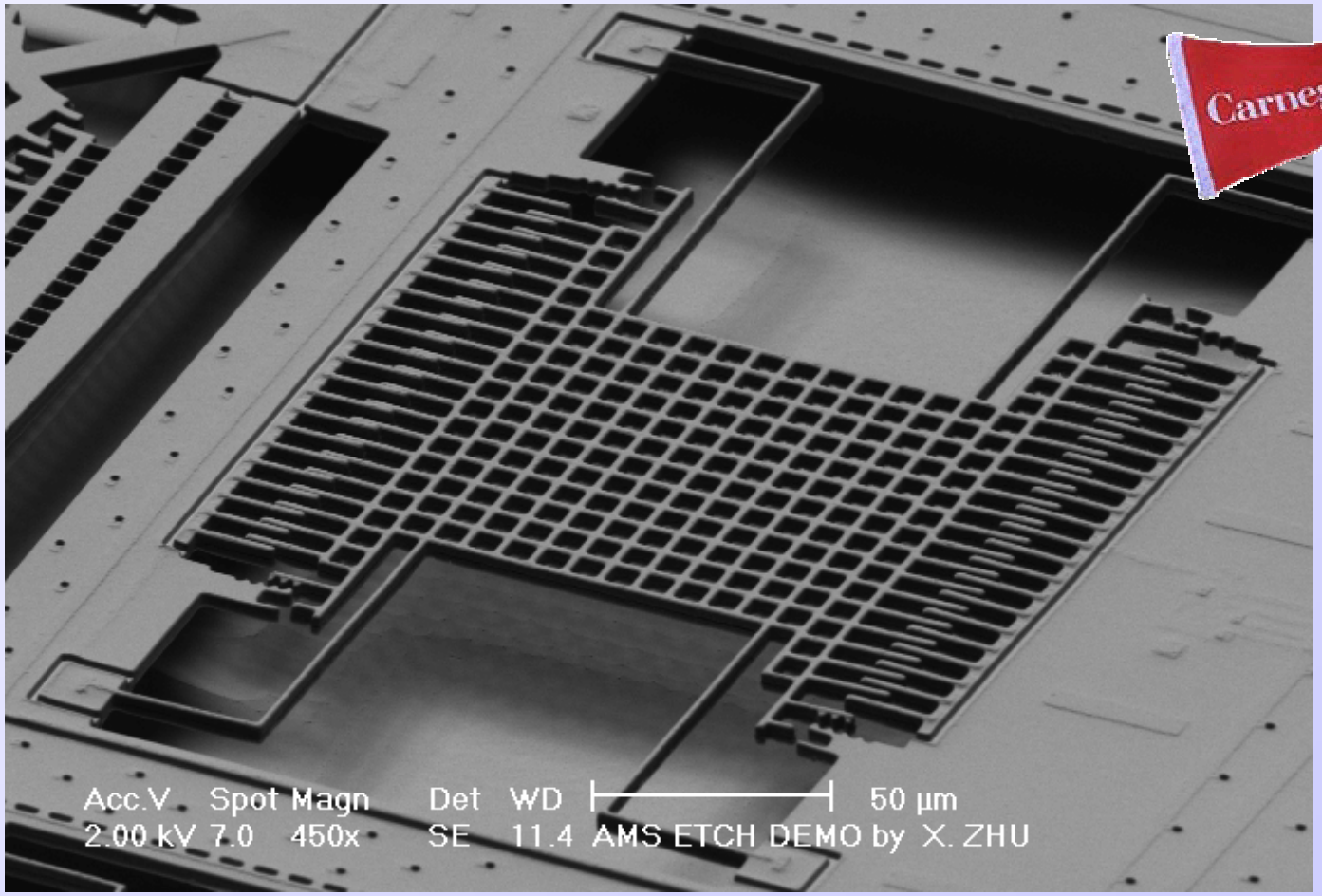






http://www.memsic.com

ASIMPS Post-CMOS Micromachining

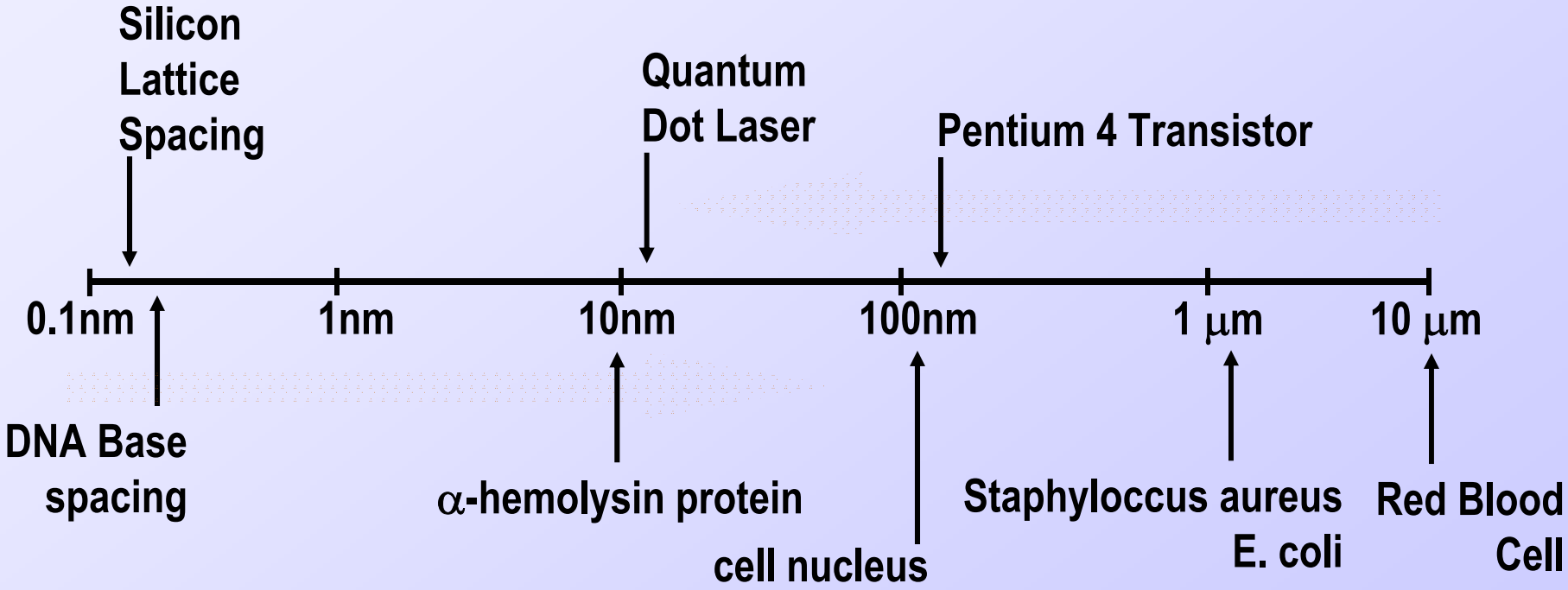


ASIMPS: AMS 0.6 µm, 3-metal

http://www.ece.cmu.edu/~mems/projects/asimps

Scales

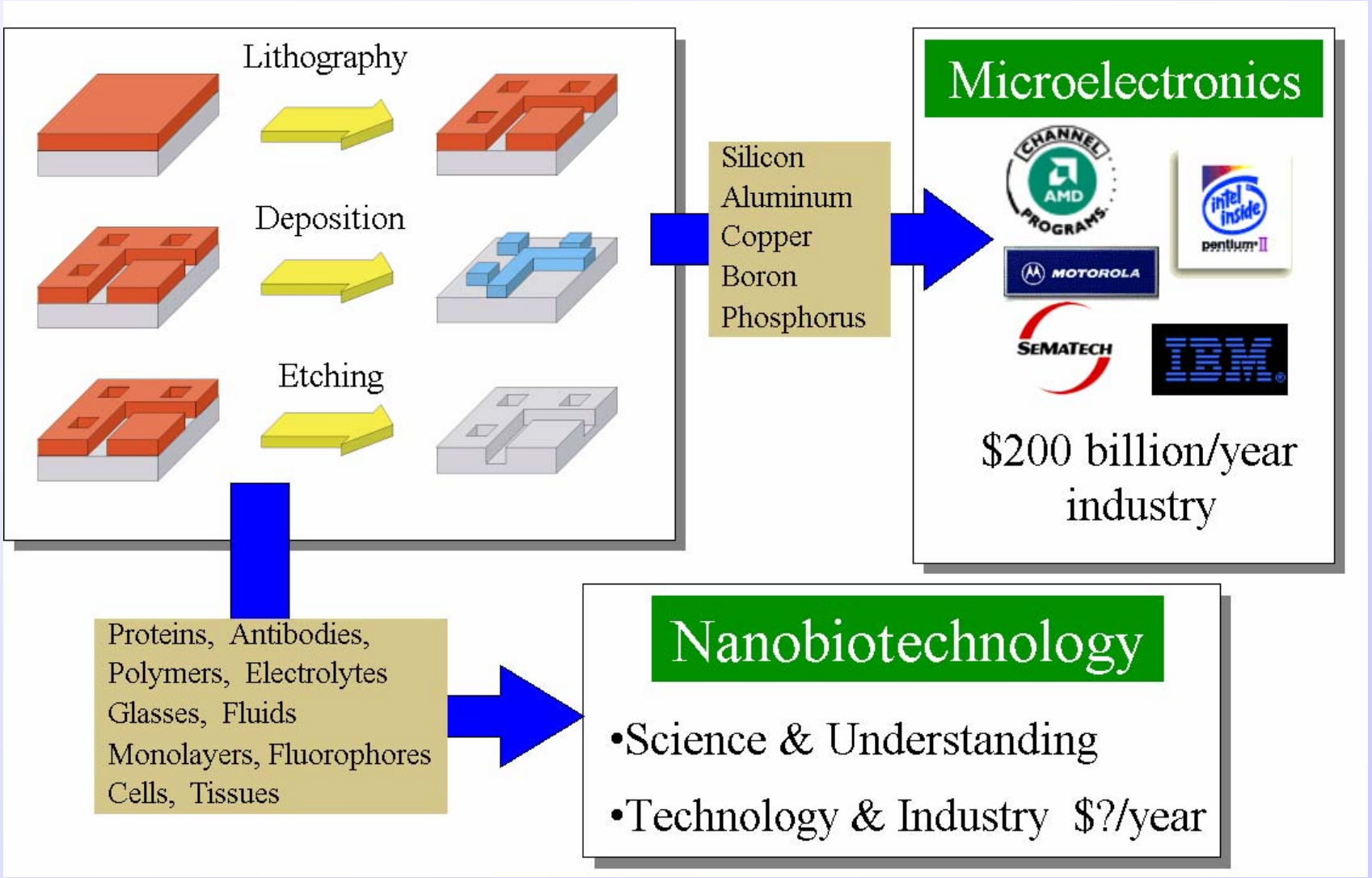
Electronics: Top-Down



Biolotechnology: Bottom-Up

Human DNA
3 billion base pairs
1 meter total length

Nanobiotechnology = Nanofabrication + Biotechnology



H. Craighead (Cornell)

http://www.nbtc.cornell.edu/Course/Lectures/One/Lectureone_files/frame.htm

Single Molecule Manipulation and Measurement: SM^3

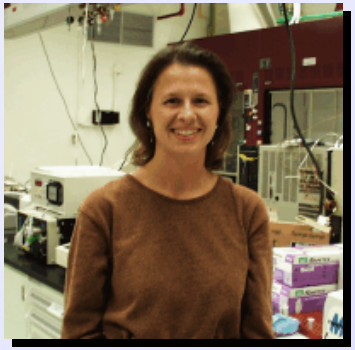
Michael Gaitan

MEMS Project
http://mems.nist.gov

September 9, 2003
NSA Visit

CSTL

John Kasianowicz, Biophysicist
Protein Nanopores



Laurie Locascio, Biomedical Engineer
Microfluidic Systems

John Marino, Biochemist
NMR Proteins

PL

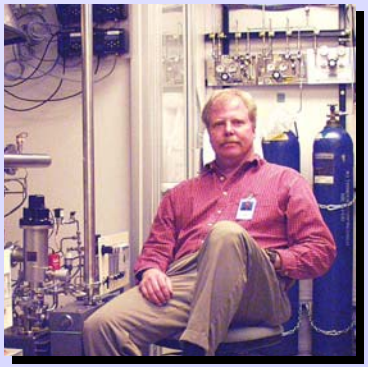
Lori Goldner, Physicist
Nano-Optics

Angela Hight Walker, Chemical Physicist
Molecular Spectroscopy

David Nesbitt, Chemical Physicist
Single Biomolecule Fluorescence

EEEL

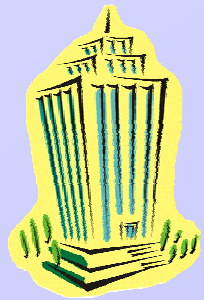
Michael Gaitan, Electrical Engineer
MEMS and Nanofabrication



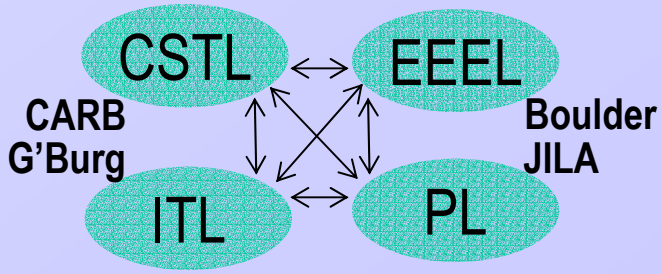
John Moreland, Physicist
Nano-Magnetics and MEMS

ITL

Vince Stanford, Mathematician
Signal Analysis



NIH



SM^3 Program Objective

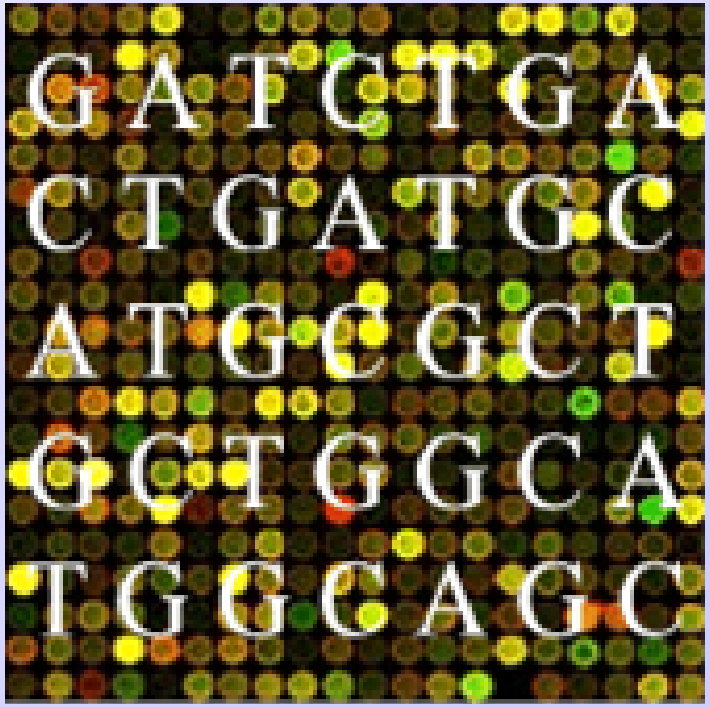
To develop and integrate new measurement methods to transport and probe structure, function, and dynamics of ***single biomolecules***

DNA, RNA, and Proteins

NIST Role
Measurements and Standards

Industry trend is smaller sample size

- genomics
- proteomics
- microfluidic systems
- lab-on-a-chip
- chem/bio sensors



Gene Chip

SM3 Deliverables

Measurement

- methods
- platform
- protocols
- standards
- data

$1B Proposed for DNA Testing
Washington Post, March 12, 2003

Measurement Challenge

Complete structural and functional measurements on single molecules.

How to isolate them?

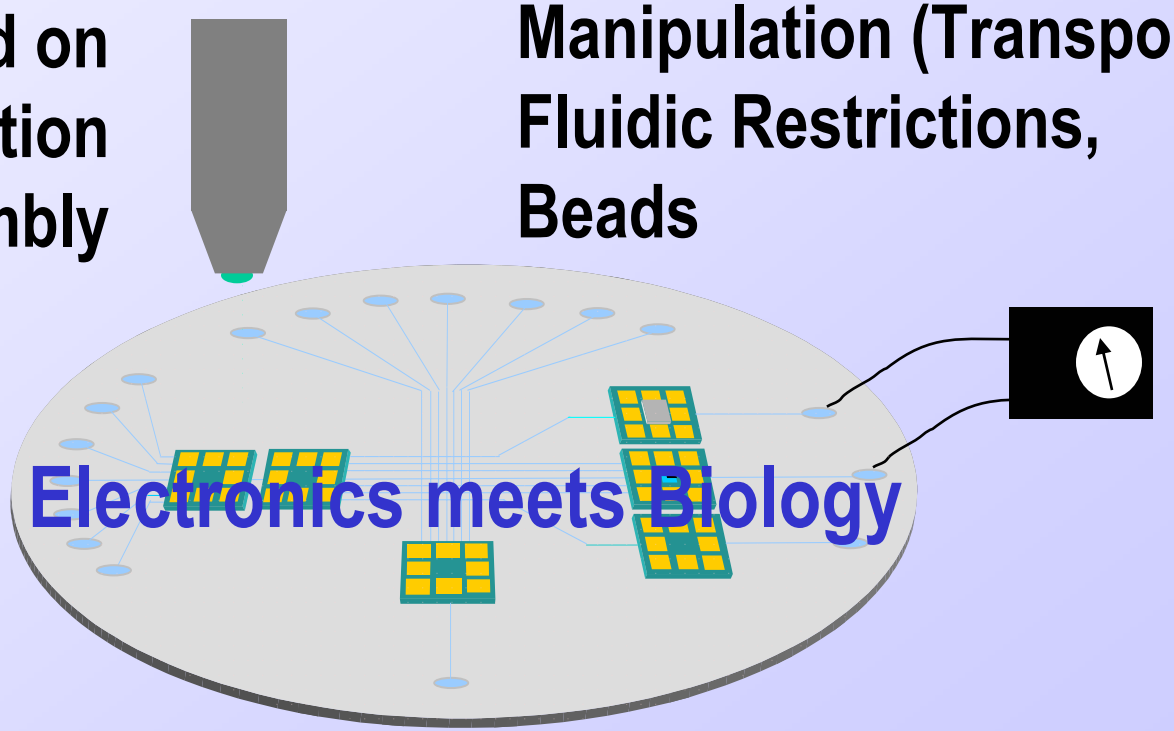
How to measure them?

Technical Approach

NanoBioTechnology Platform

Platform based on
Nanofabrication
Molecular Assembly

Manipulation (Transport):
Fluidic Restrictions,
Beads

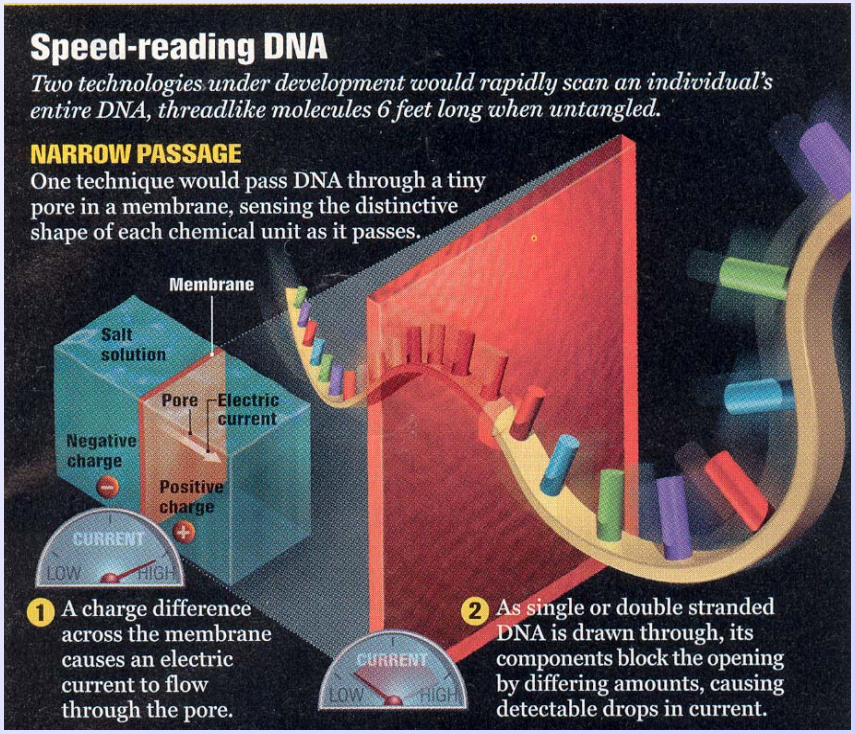


Measurements:
Electronic, Optical, Force

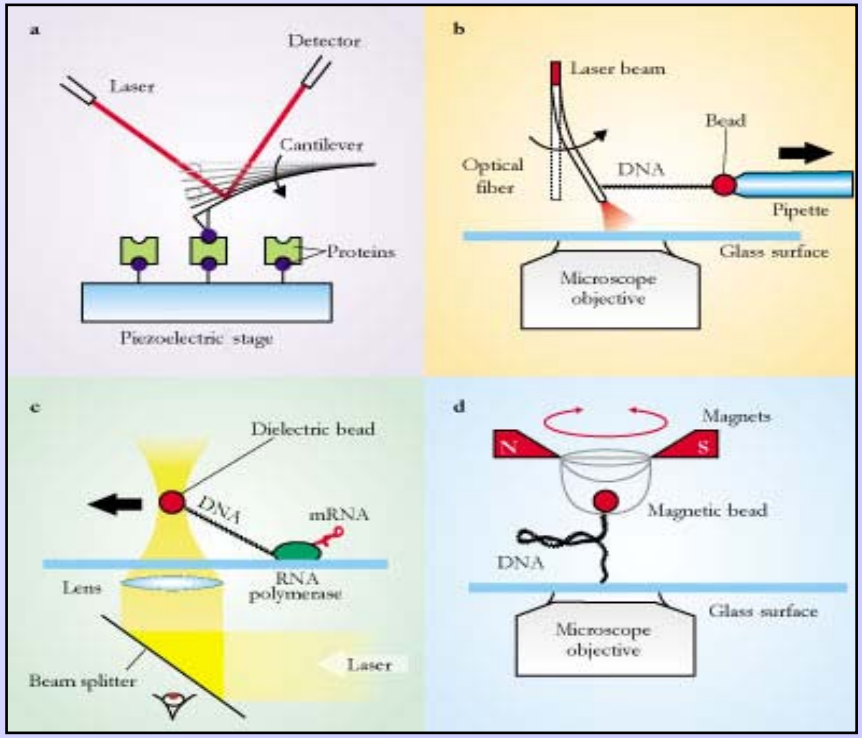
Manipulation (Capture):
Vials, Beads, Arrays

Manipulation and Measurement

Electronic … Optical … Mechanical

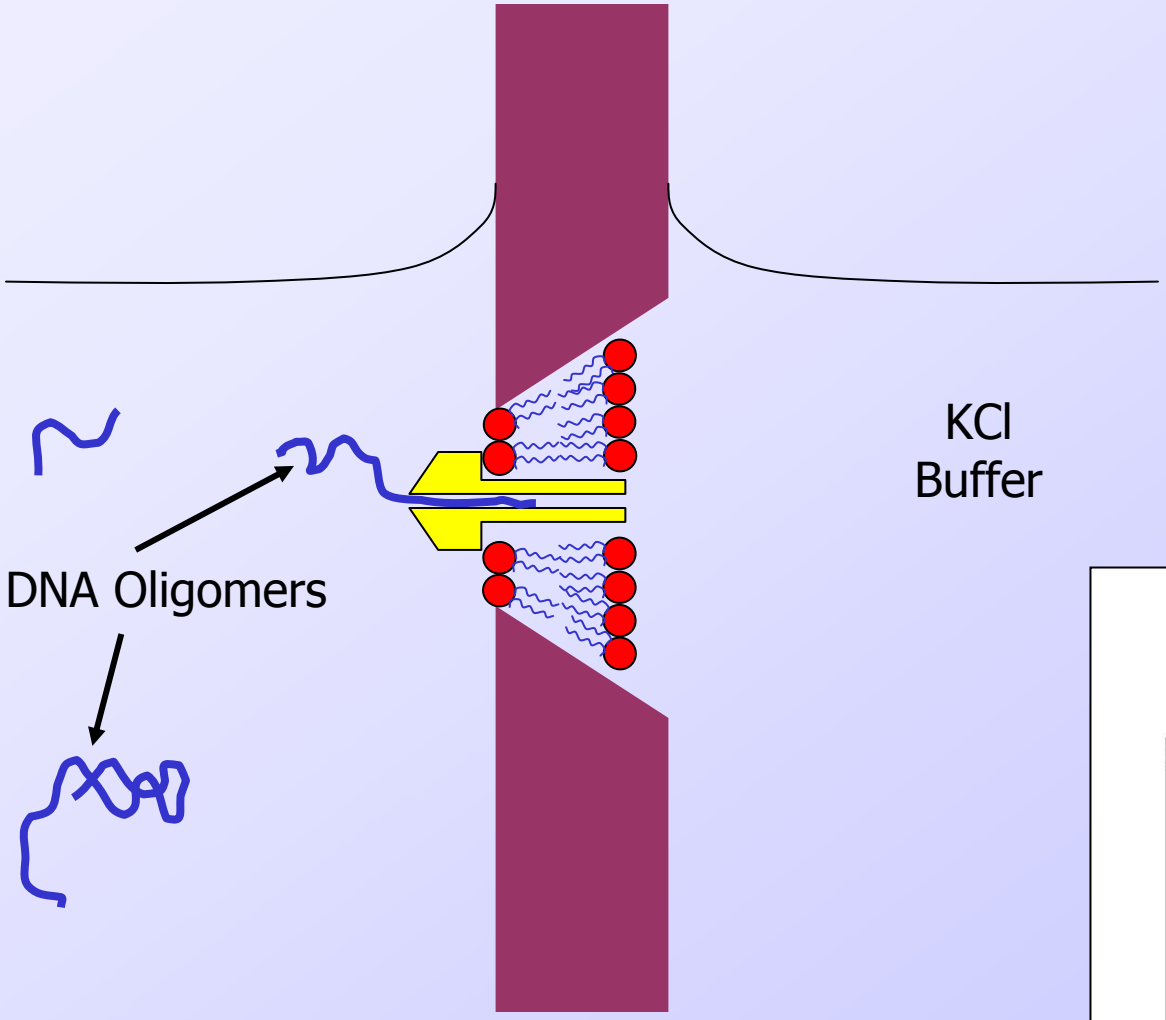


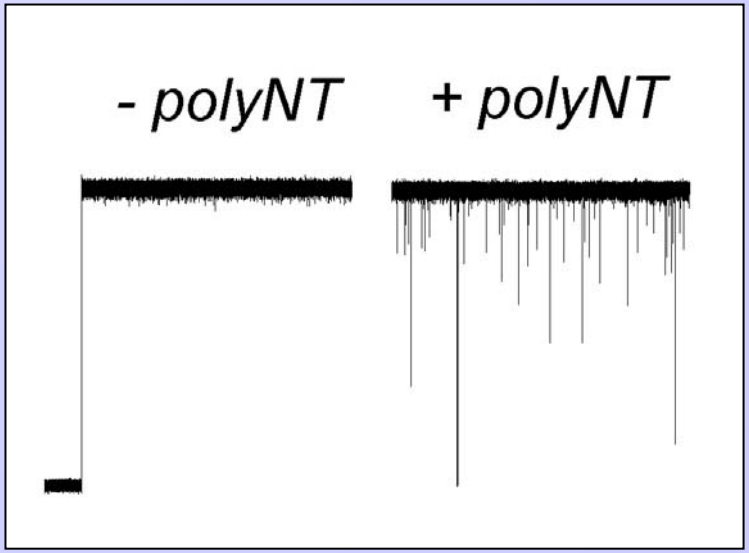
US News and World Report, May 2002



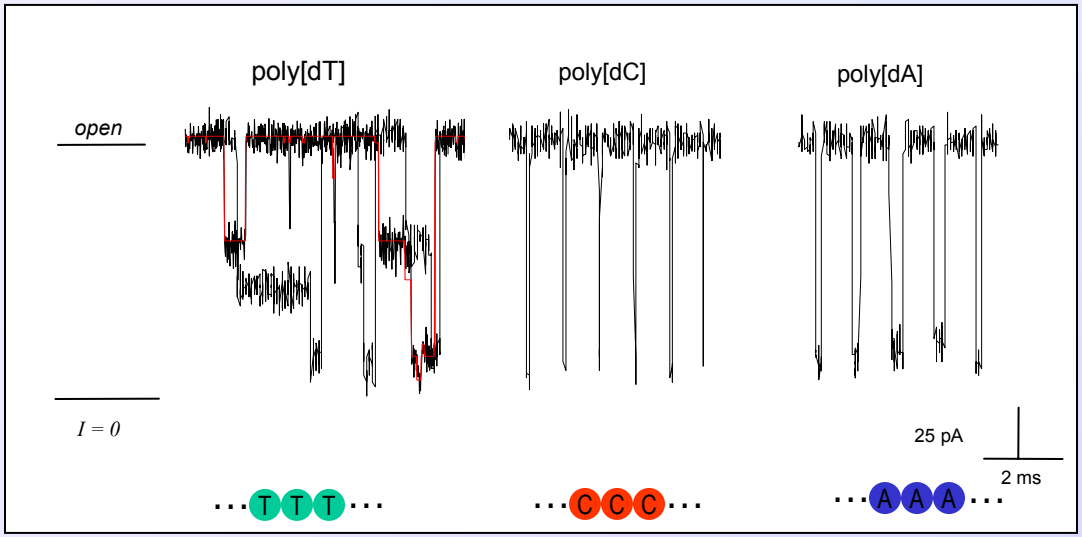
Physics Today, October 2001

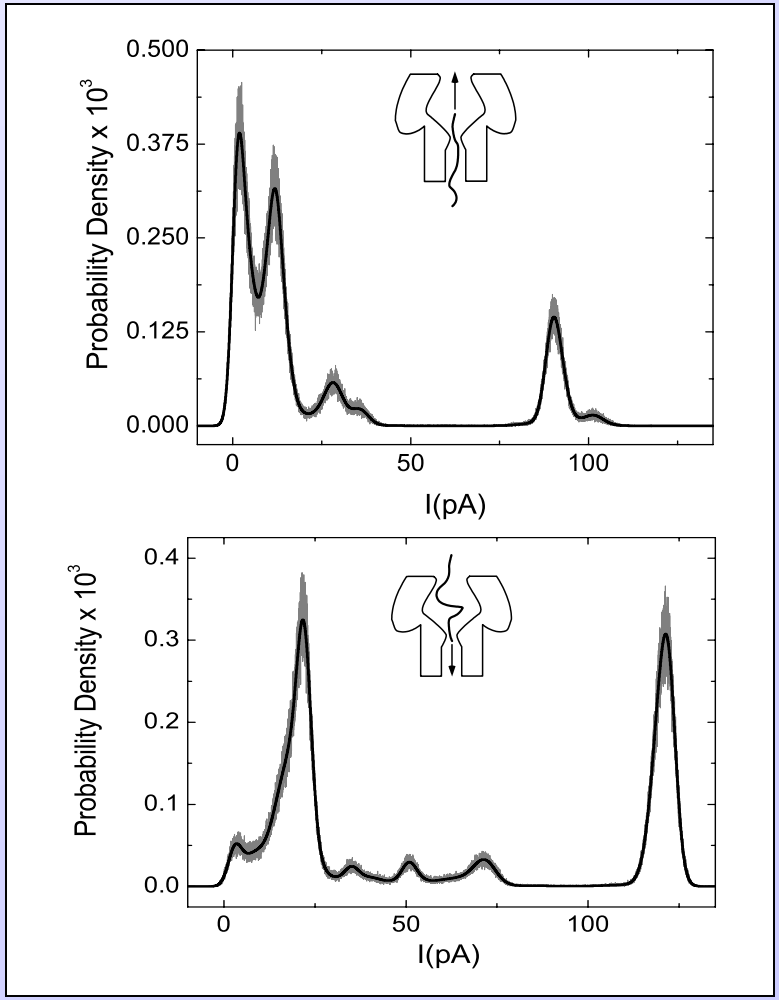
Protein Nanopores





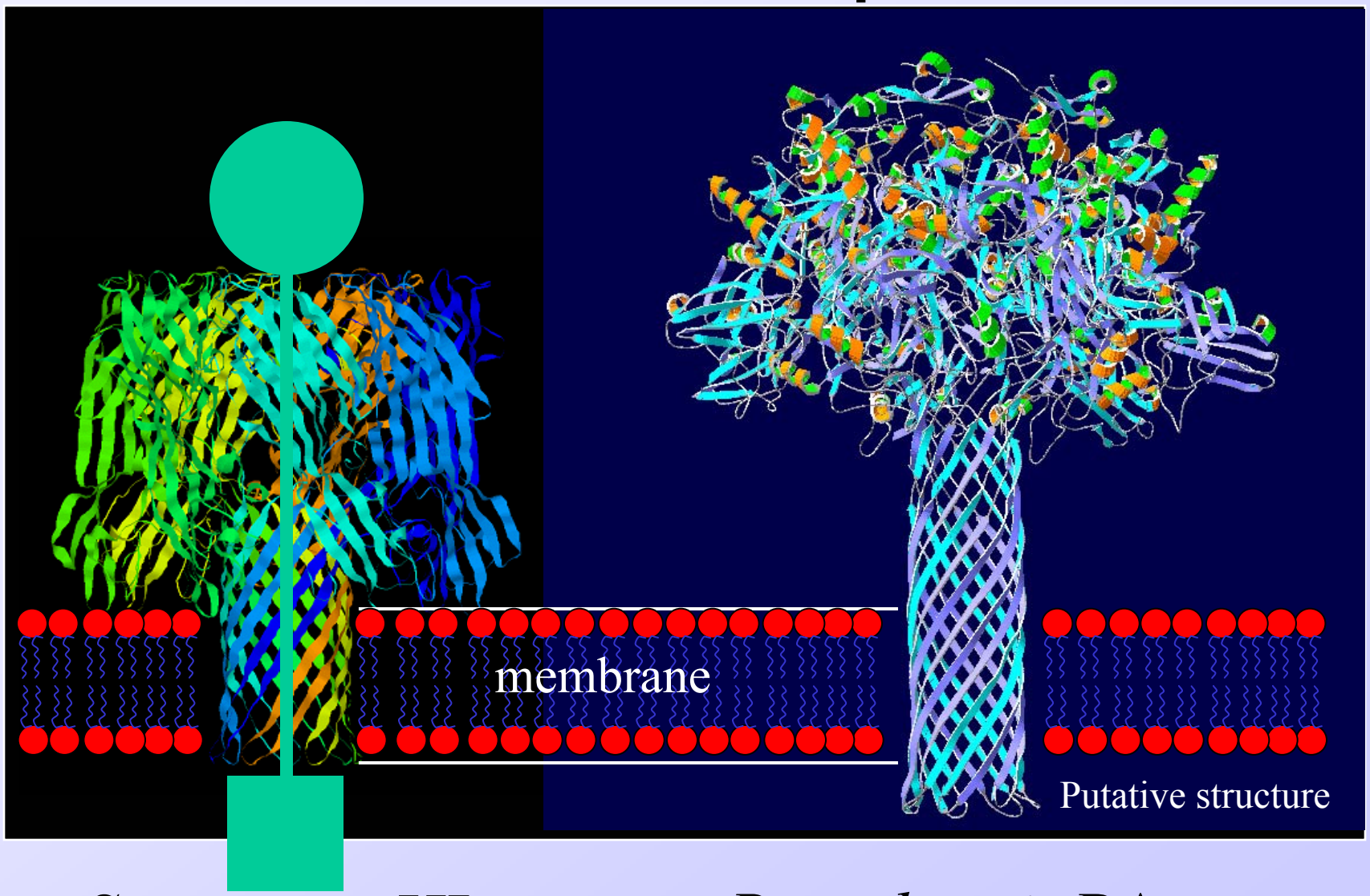
Data Analysis
Decoding Algorithms





- Identical length DNA molecules cause different signals
- Signal content depends on the transport direction
- Building computer systems & software to decode information in molecules

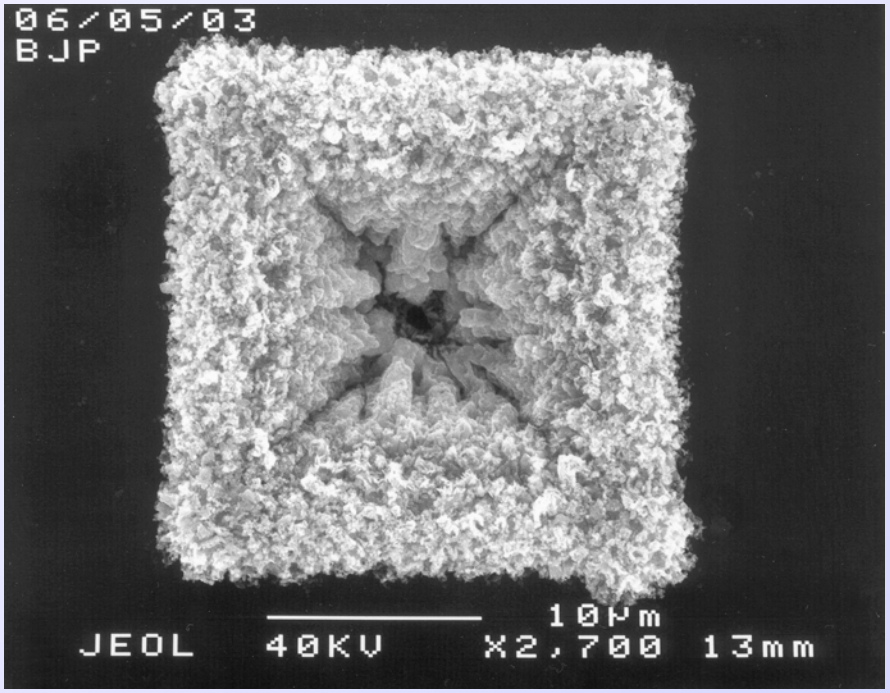
Protein Nanopores

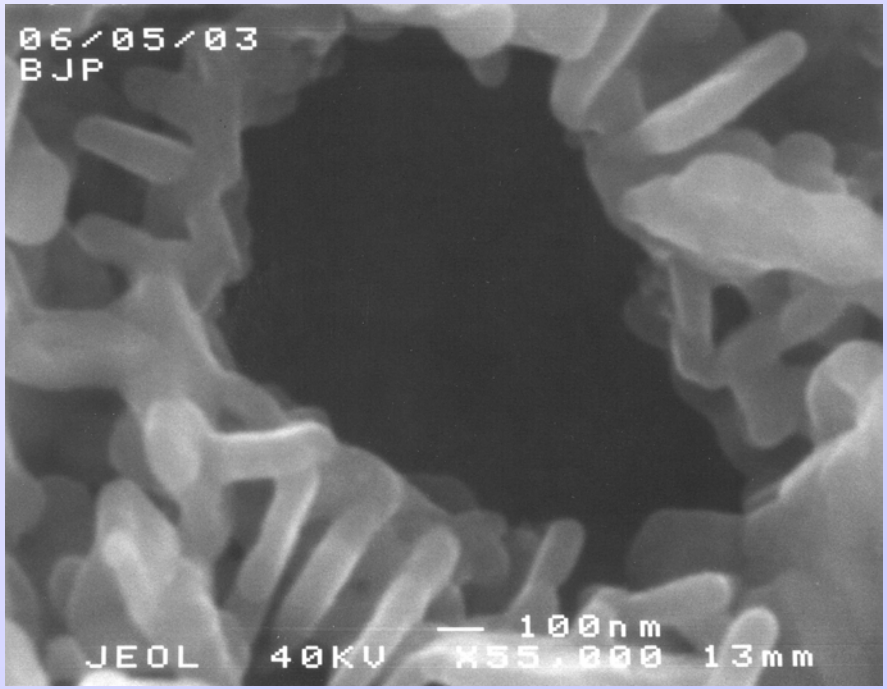


S. aureus αHL

B. anthracis PA_{63}

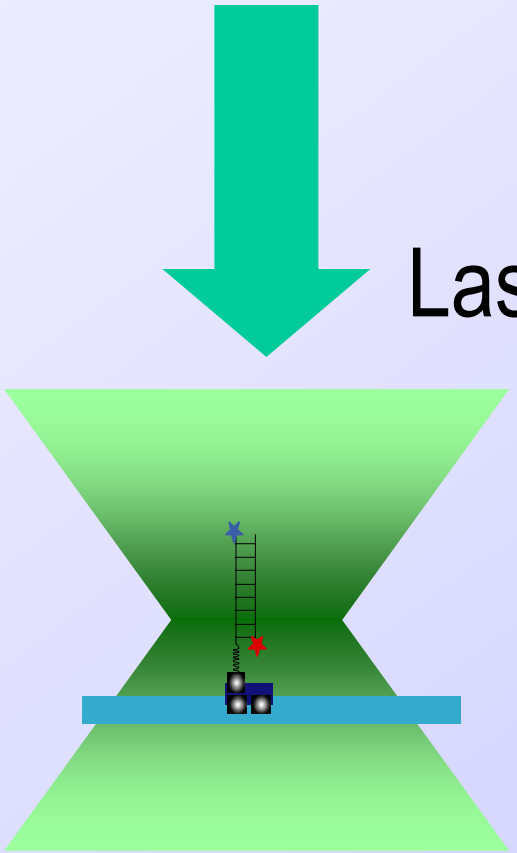
Solid State Nanopores





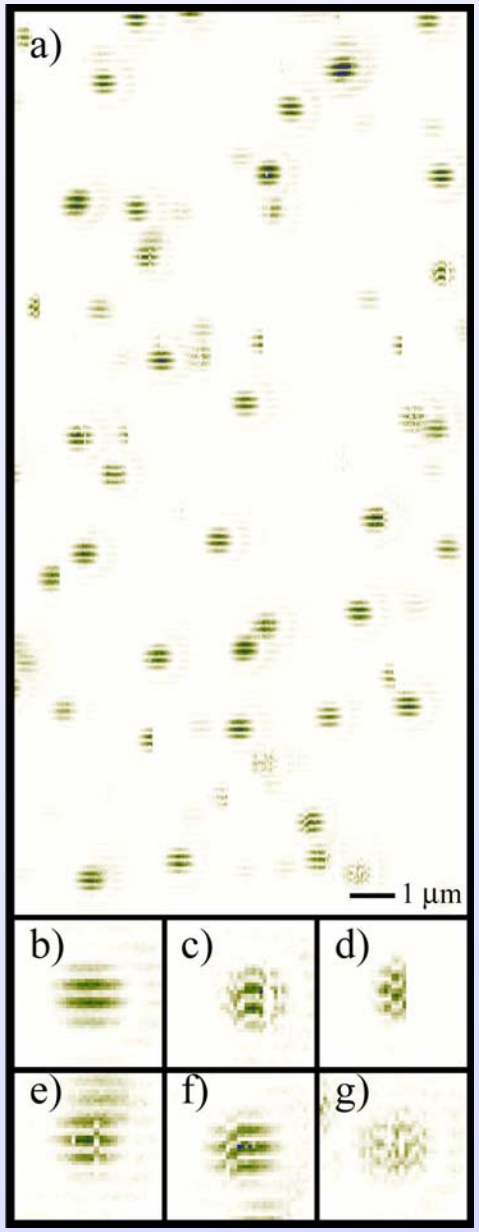
Electroplated

Single Molecule Optical Measurements



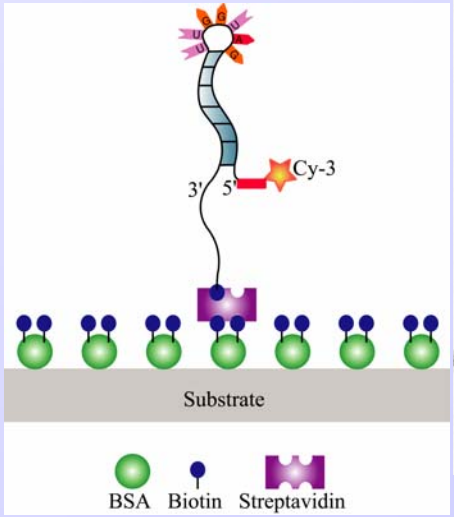
Laser Light

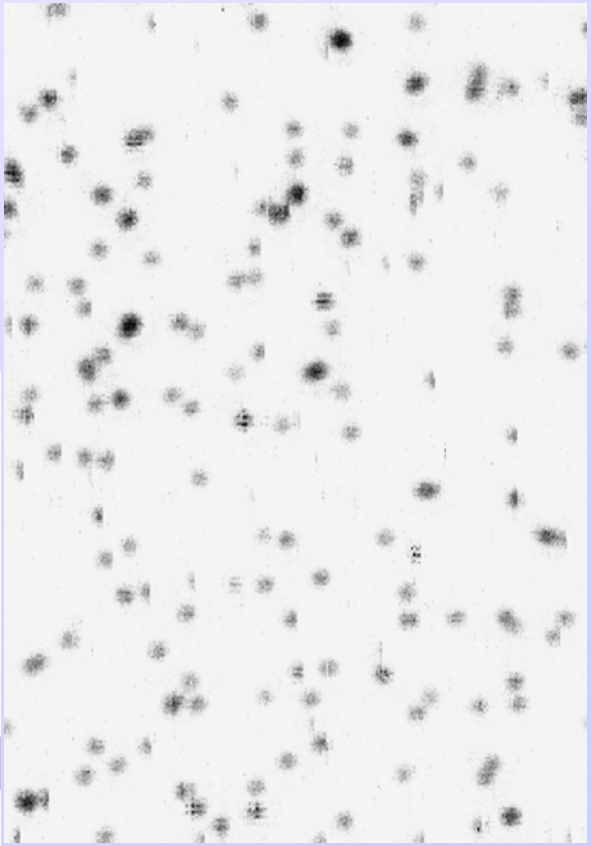
Activity of surface attached biomolecules



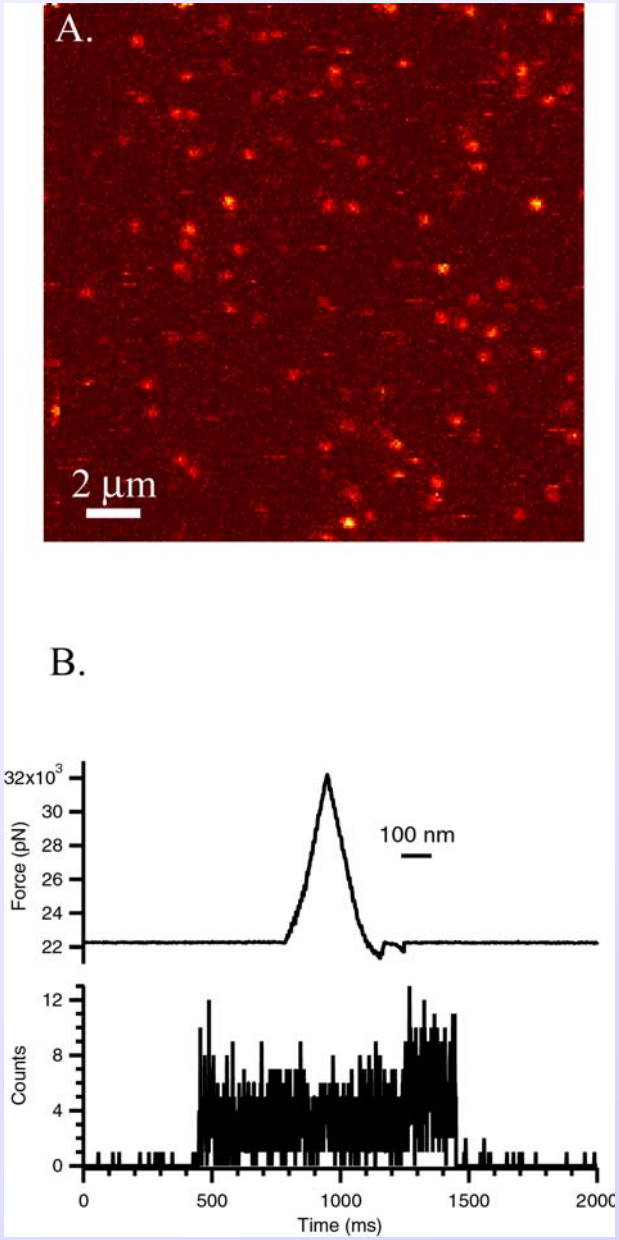
Dye molecules in polystyrene

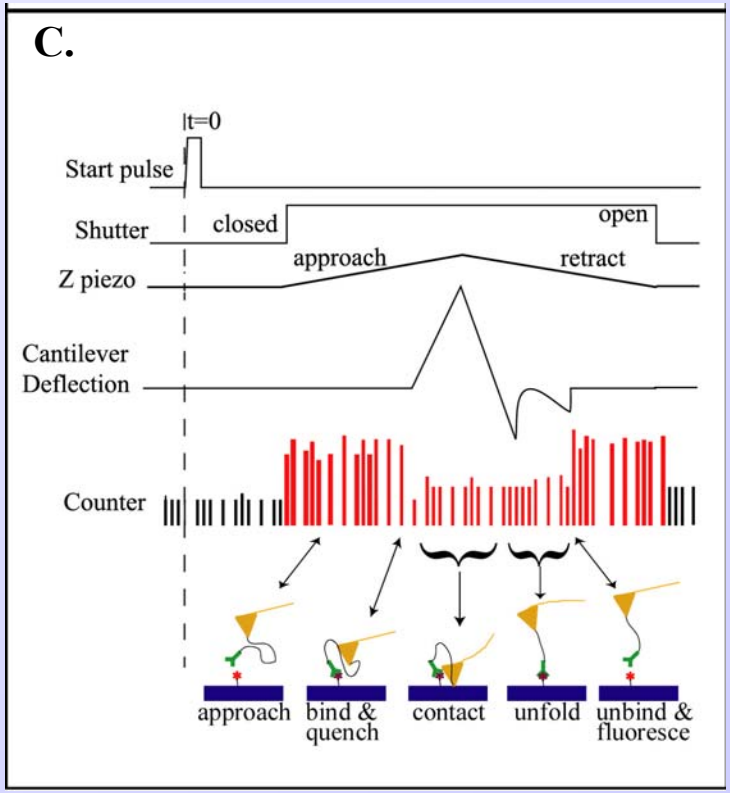
RNA on biotinylated glass





Simultaneous force and optical measurements: antibody/antigen interactions





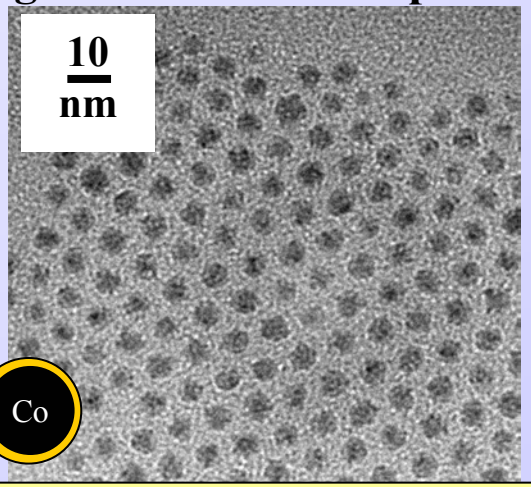
Example: Alexa fluor 488 attached to glass. Anti-alexa attached to AFM tip. Anti-alexa quenches the fluorophore.

Single Molecule Vibrational Spectroscopy
Surface Enhanced Raman Scattering (SERS)

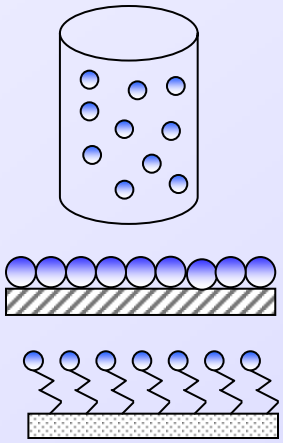
Enhancement of Raman cross section can be as large as 10^{15} thereby permitting single molecule detection, however, nanostructure morphology, concentration, material, etc. are all critical to obtaining reproducible SERS substrates.

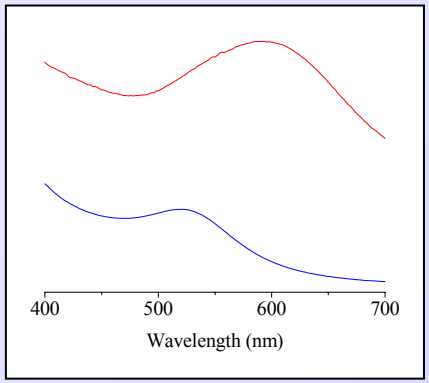
Goal: Quantitative SERS

Magnetic Cobalt Nanoparticles

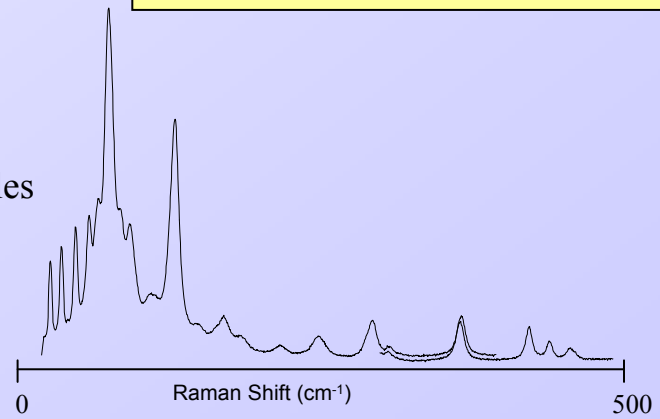


Need gold-coated Co nanoparticles for SM sensitivity **and** magnetic manipulation

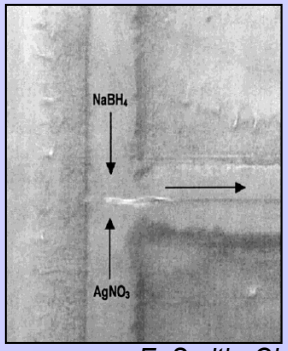




UV-VIS of 5 nm Au nanoparticles



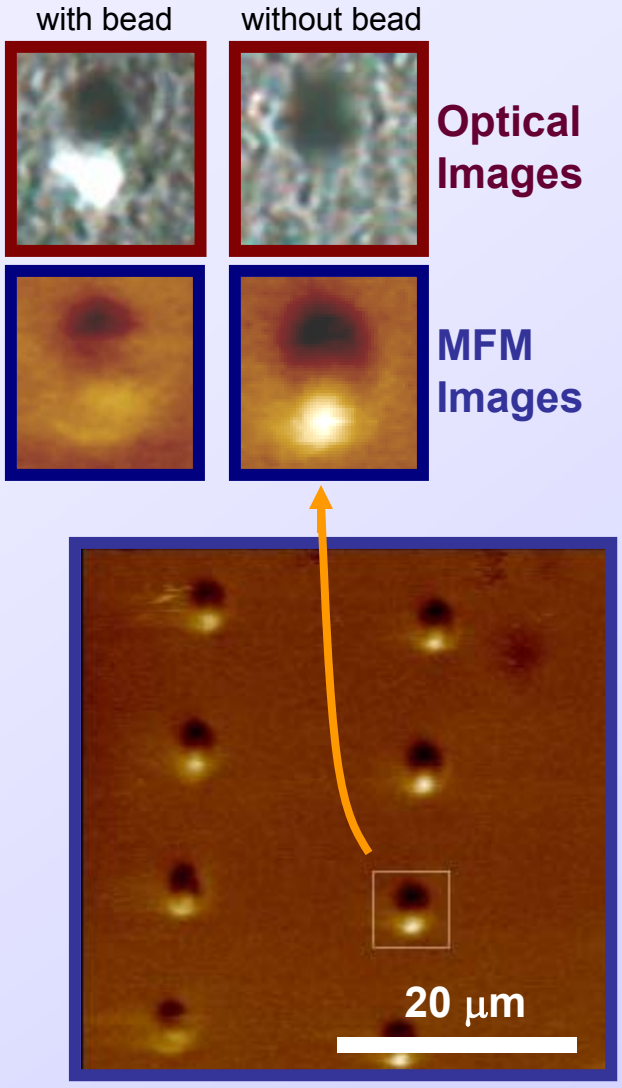
Vibrational Spectroscopy *in situ* in a MEMS device



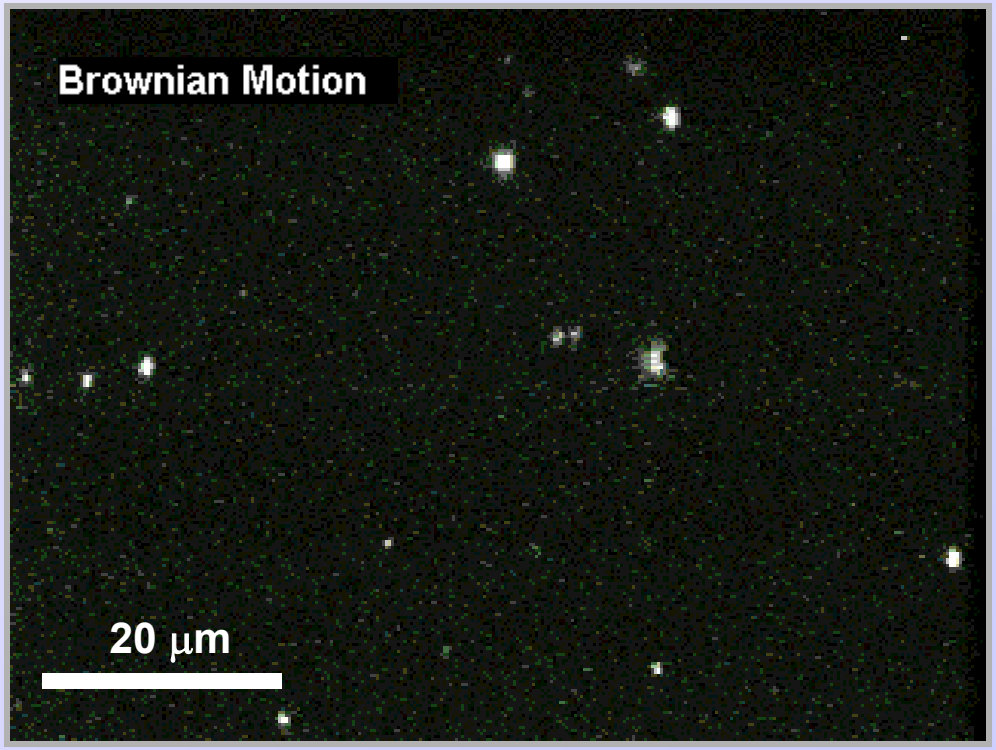
Concentrate on low frequency vibrational modes--**detailed structural info!!**

E. Smith, Glascow

Magnetic bead trapping and position control

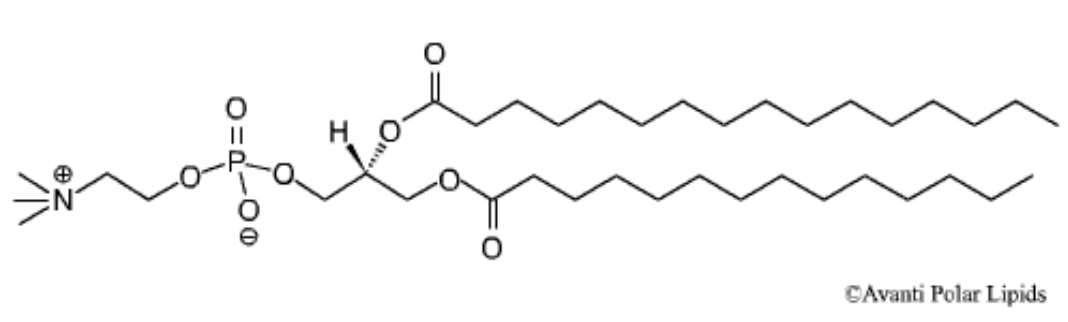


Trapping magnetic beads



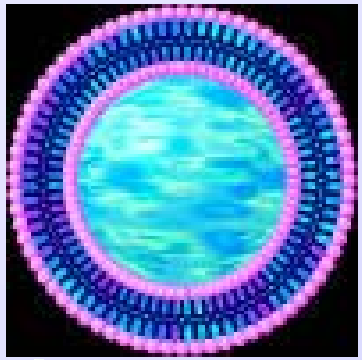
Florescence microscopy video of magnetic beads coated with FITC dye near NiFe magnetic traps with and without applied field (H_{bias} = 1 kOe).

Nanovials - Liposomes

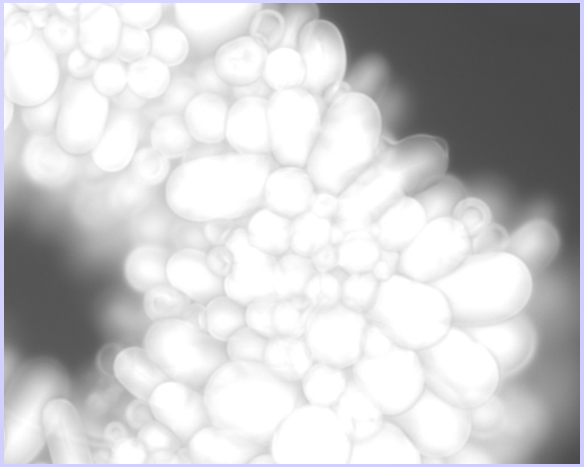


DLPC (C_{12})
DMPC (C_{14})
DPPC (C_{16})

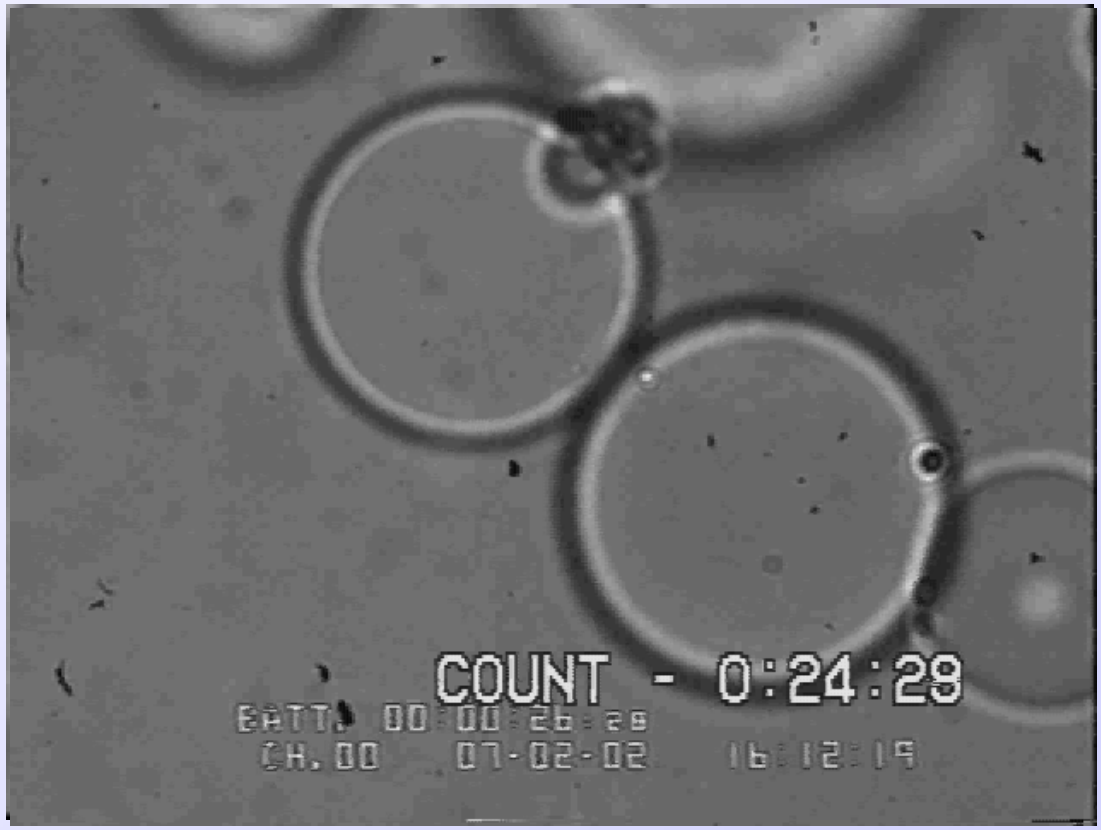
Disperse in water and vesicle formation is spontaneous



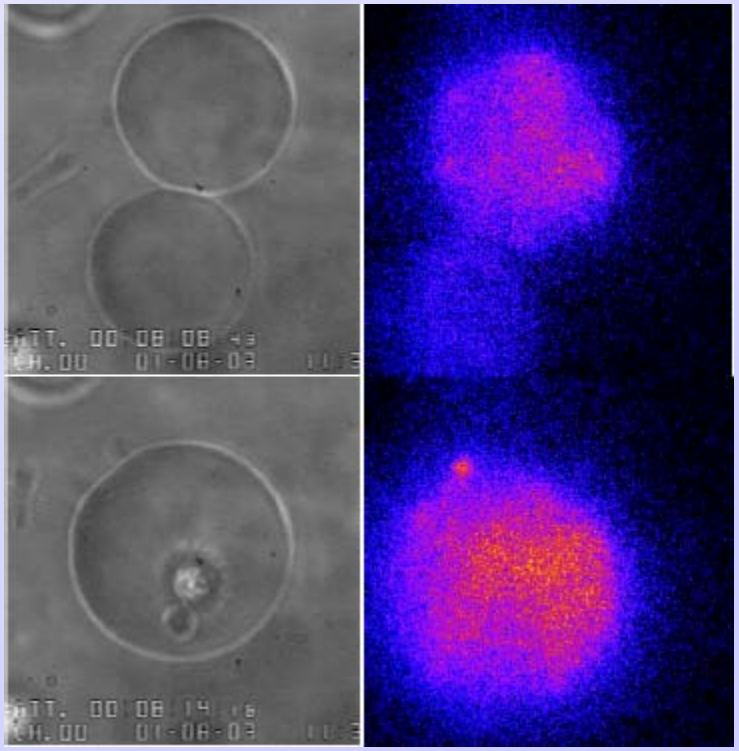
Spherical vesicle



Liposomes
Nanoreaction Vials



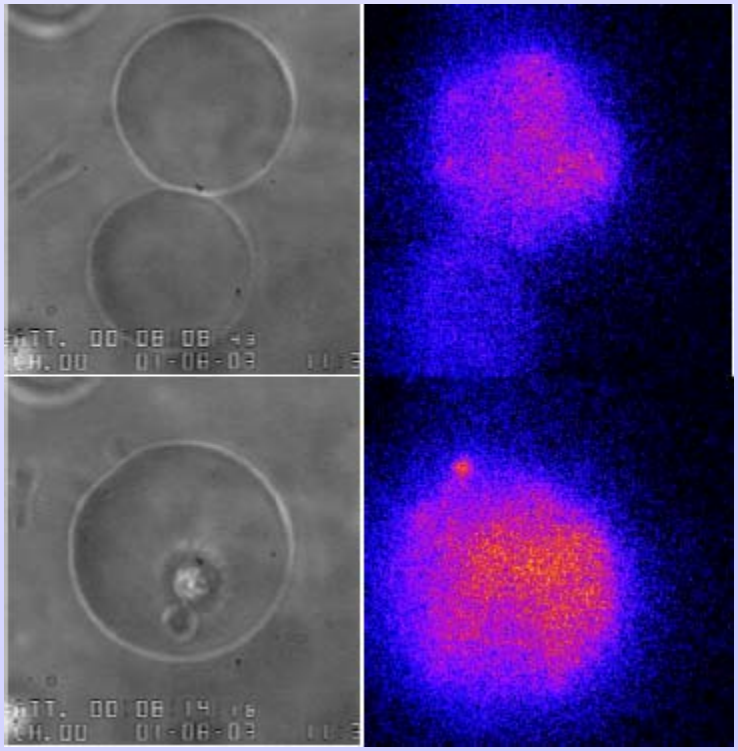
Reactants encapsulated in single liposome or in 2 separate liposomes and fused



Independently controllable environment, study reaction kinetics, single molecule events

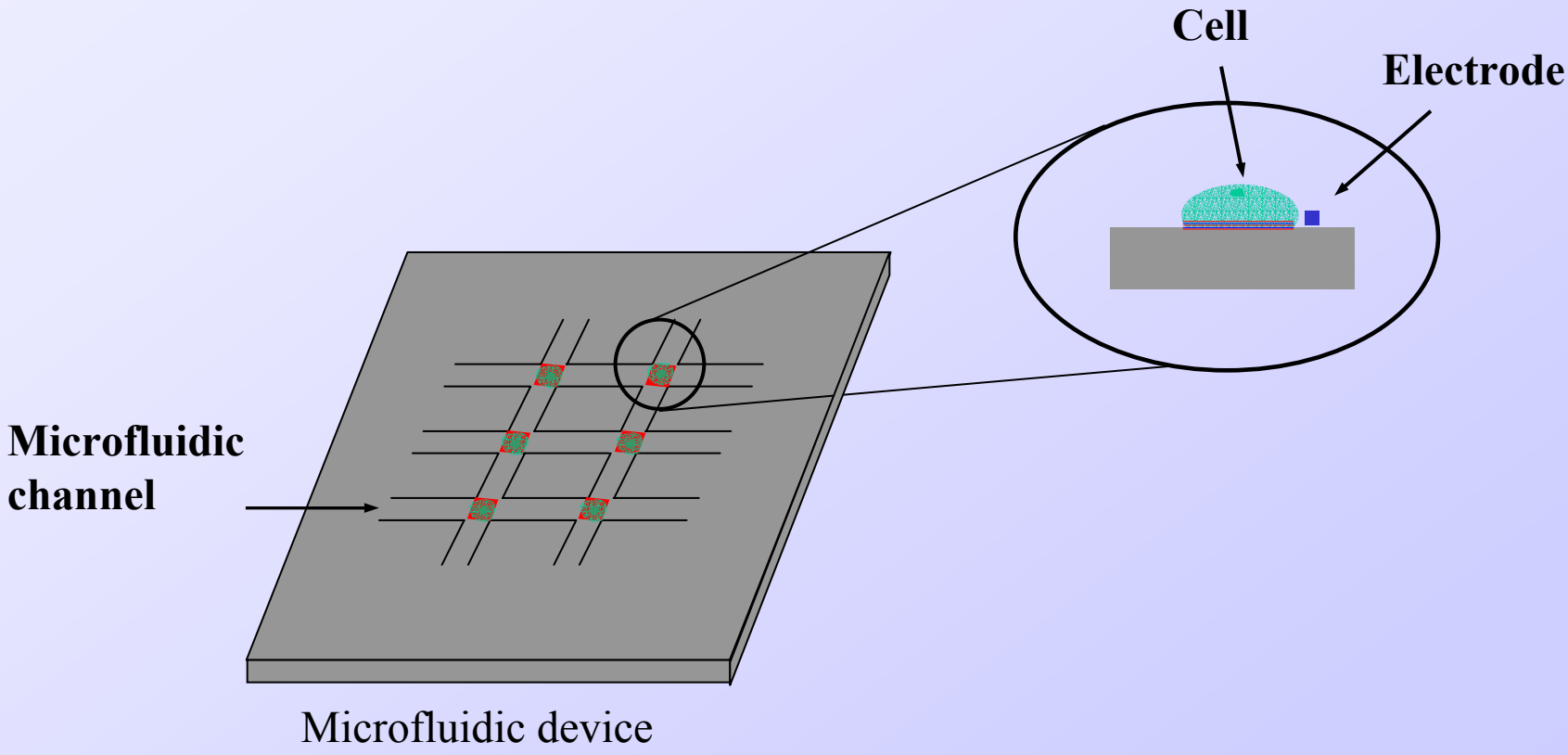
Liposomes
Nanochannels

Pull a nanochannel from a liposome

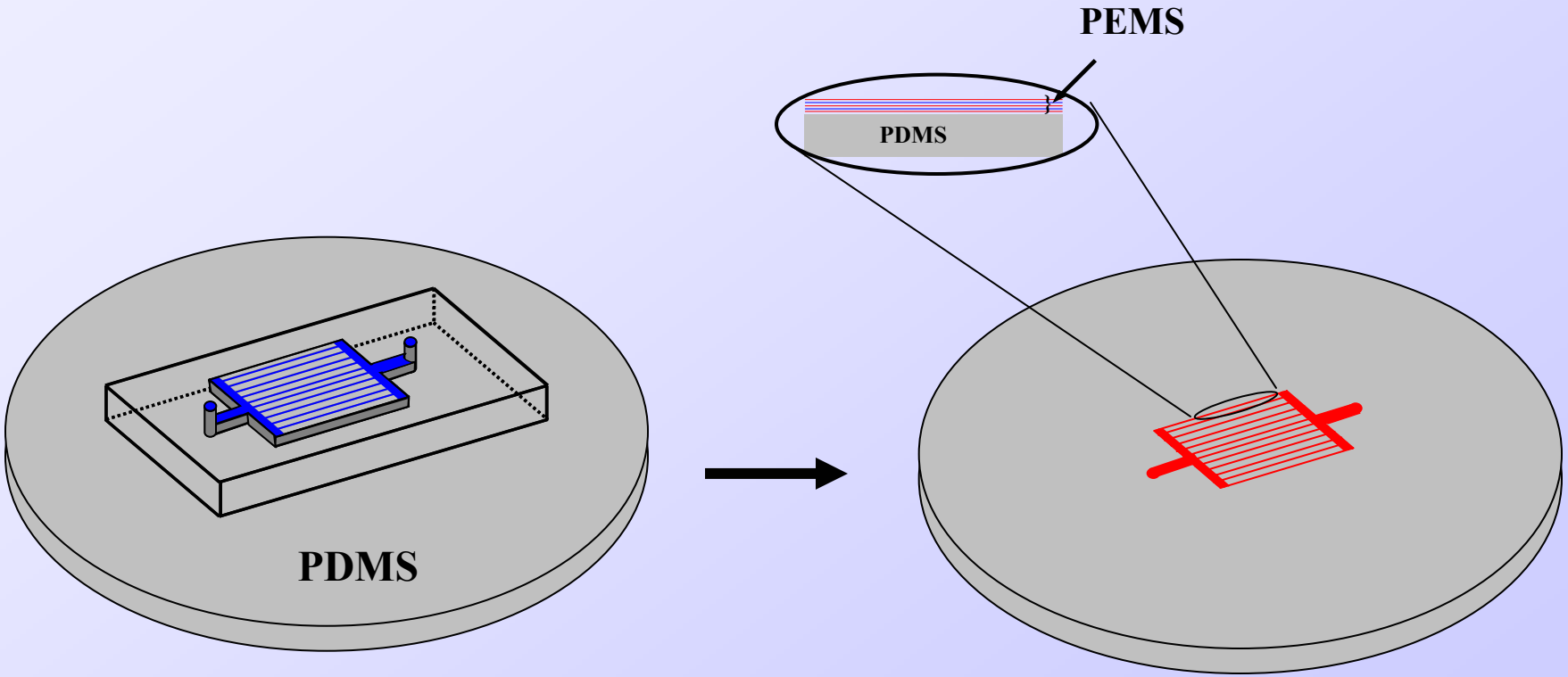


Independently controllable environment, study reaction kinetics, single molecule events

Cellular BioElectronic Interfaces



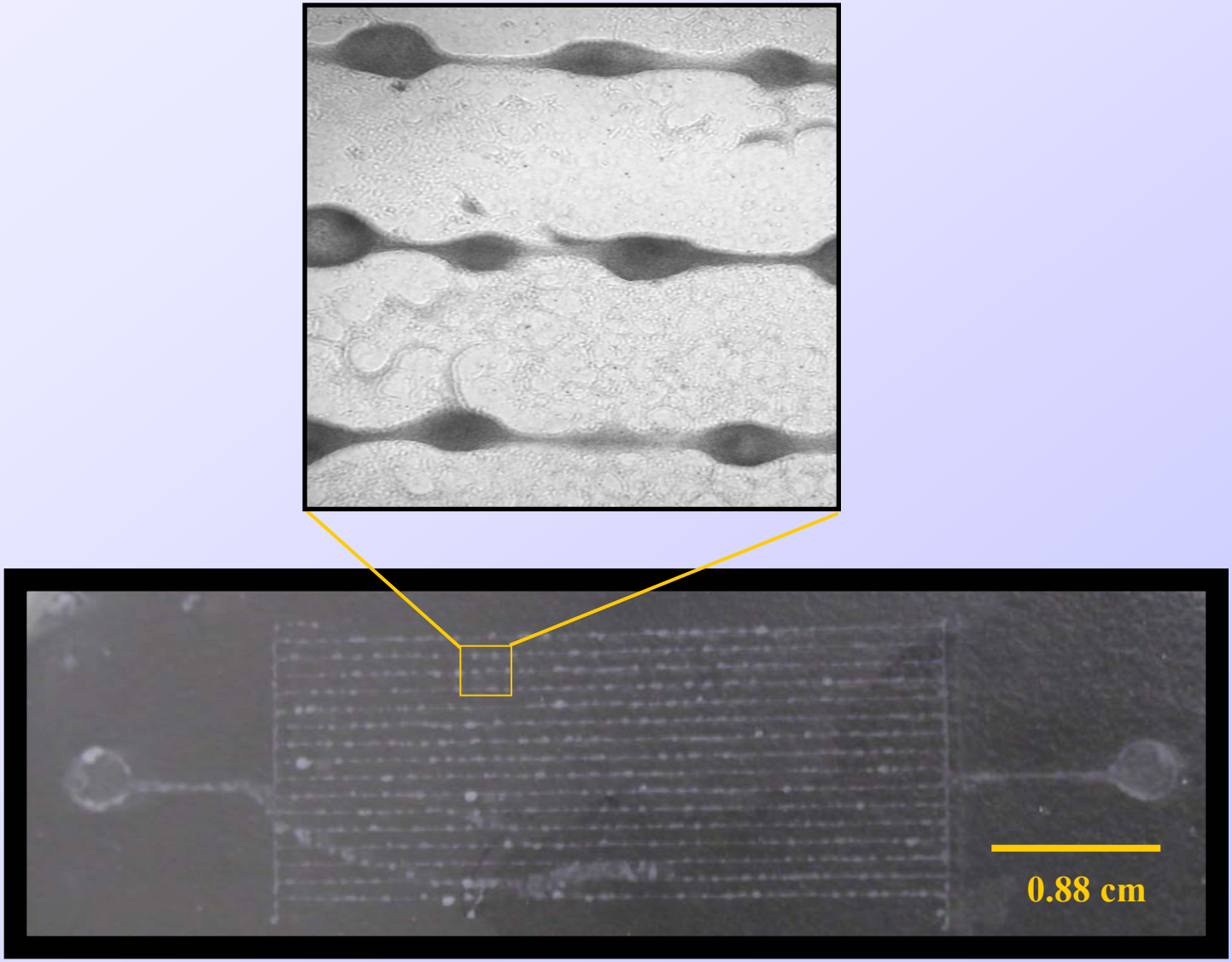
Patterning PDMS with PEMS



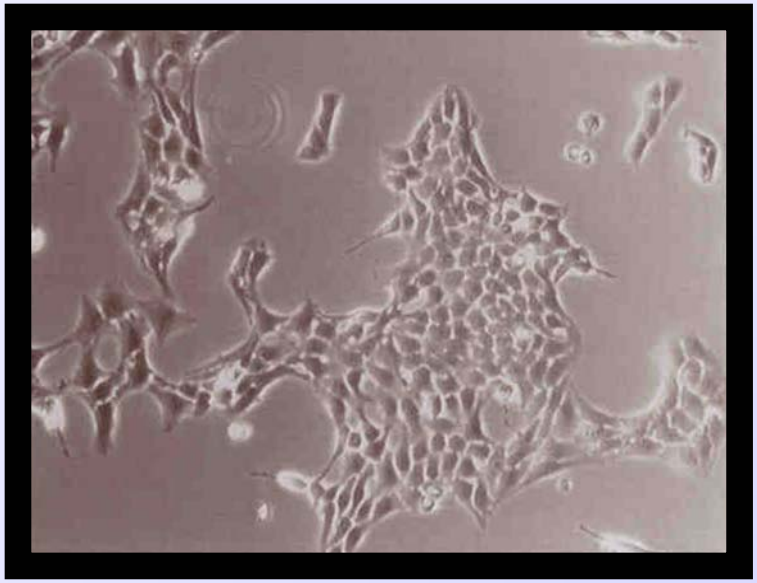
Polyelectrolyte Multilayers (PEMS)

Polydimethylsiloxane (PDMS)

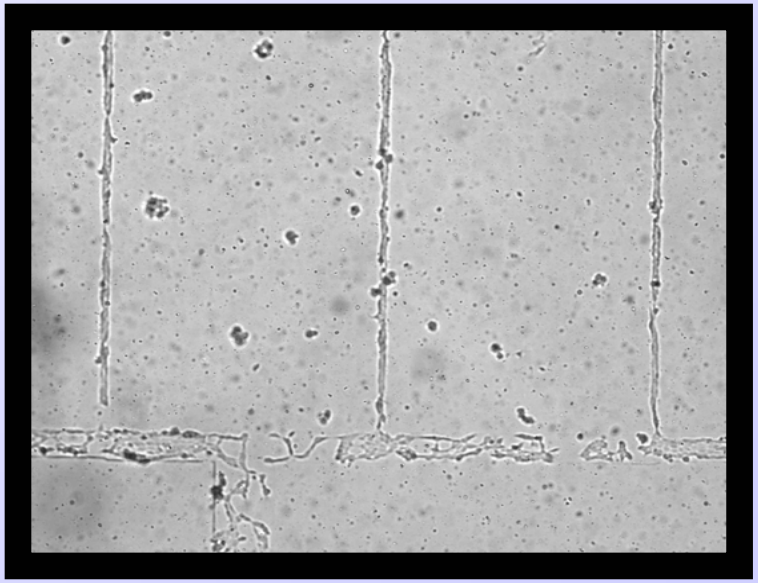
Two weeks growth of retinal cells on poly(ethyleneimine).
Cells are covering all the polycation area.



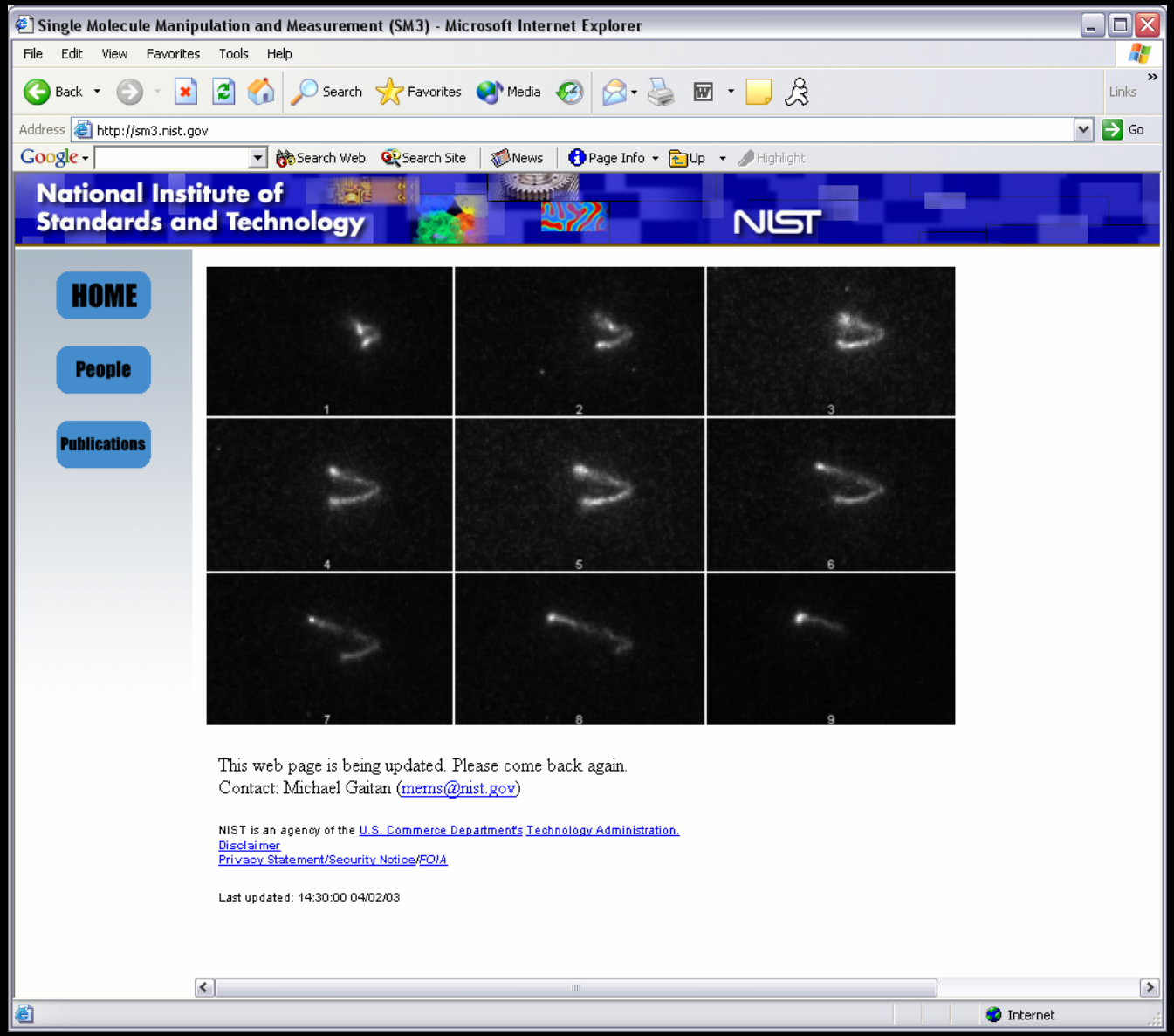
Non-Patterned Cell Growth vs. Patterned Cell Growth



Retinal cells cultured in polystyrene culture flasks.



Overnight growth of retinal cells on poly(allylamine hydrochloride) patterned lines.



http://sm3.nist.gov